

**How an Energy Awareness Application Affects User Behavior:
A Case Study**
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Helsinki 7.10.2014

Master's Thesis
UNIVERSITY OF HELSINKI
Department of Computer Science

Tiedekunta – Fakultet – Faculty		Laitos – Institution – Department	
Faculty of Science		Department of Computer Science	
Tekijä – Författare – Author			
Maria von Kügelgen			
Työn nimi – Arbetets titel – Title			
How an Energy Awareness Application Affects User Behavior: A Case Study			
Oppiaine – Läroämne – Subject			
Computer Science			
Työn laji – Arbetets art – Level		Aika – Datum – Month and year	Sivumäärä – Sidoantal – Number of pages
Master's thesis		7.10.2014	66 + 7
Tiivistelmä – Referat – Abstract			
<p>A significant number of people have problems with the batteries of their mobile devices. There are several energy saving applications available to tackle those problems. Most of them increase battery life mostly by automatically closing applications or operations. The user is for the most part unaware of what the energy saving application actually does. Therefore, even though the battery might last somewhat longer, the user may continue using behavioral patterns that drain the battery.</p> <p>There is little evidence to support the assumption that battery awareness applications lead to behavioral changes. Therefore, we decided to conduct a research on how a mobile awareness application called Carat is used, and how the behavior of its users changes over time.</p> <p>The study was carried out in two phases. In the first part of the study, we conducted a user survey, and studied the Carat log data of the devices represented in the survey. We found out that the behavior changes over time; there were significant differences between new Carat users, and the more experienced ones. The more experienced users had reduced their use of problematic applications more, were interested in different features of Carat, and opened it less often.</p> <p>In the second part of the study, we studied how new Carat users used Carat and what they thought of using it. They were interviewed twice, and they also wrote in a web diary about their experiences. We found out that the main difference in their thinking was the increase in overall awareness about applications as something that affects battery life. We also found out that inadequate, uninteresting and unclear information causes confusion and frustration, and decreases the likelihood of users sticking with Carat.</p> <p>ACM Computing Classification System (CCS): Human-centered computing → Human computer interaction (HCI) Human-centered computing → User studies <i>Human-centered computing</i> → <i>Mobile devices</i></p>			
Avainsanat – Nyckelord – Keywords			
Energy awareness application, Mobile devices, Human Computer Interaction			
Säilytyspaikka – Förvaringställe – Where deposited			
Muita tietoja – Övriga uppgifter – Additional information			

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Appendix 1: Carat usage questionnaire

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1 Introduction

Nowadays, people use a lot of mobile devices, and many encounter problems with their batteries. It is quite common to have to charge the device more than once a day. Often, people do not know how they could make their batteries last longer.

To tackle the problem, there are several energy-saving applications available [CrK07, DoZ11, OIS13, PHZ12]. These applications increase battery life usually by automatically closing applications or operations. The user is for the most part unaware of what the energy saving application actually does. Therefore, even though the battery might last somewhat longer, the user may continue to use behavioral patterns that drain the battery.

User behavioral studies in the area of mobile battery awareness are rare. There are some studies about energy awareness applications in domestic environments [ASV07, CTG08], and also some studies on battery level indicators on mobile devices [RQZ07, RaZ09]. To our knowledge, the effect of battery management advice on user behavior has not been studied in previous work.

There is little evidence to support the assumption that battery awareness applications lead to behavioral changes. Since the power consumption of smartphones also depends on user behavior, we decided to try to find out what people can do to help the battery last longer.

It requires a large user base to successfully study how this kind of application would affect behavior. Therefore, we decided to conduct a research on how a mobile awareness application called Carat is used, and how the behavior of its users changes over time. It does not do any actions by itself, but gives the user information, and a way to do some energy saving actions within the application. Carat is used worldwide in over 600,000 mobile devices, and it has been shown that using Carat helps the users

save the battery of their mobile devices [OIL12, OIS13]. Yet, very little is known about how people use Carat and what kind of behavior leads to these results.

The study was carried out in two phases. The first part of the study was conducted collaboratively by Kumaripaba Athukorala, Eemil Lagerspetz, Antti Jylhä, Adam J. Oliner, Sasu Tarkoma, Giulio Jacucci, and the present author. The results of this part of the study were published in spring 2014 [ALK14]. The second part of the study was conducted and analyzed by the present author.

In the first part of the study, we conducted a user survey, and received over 1,000 submissions. In addition to the survey responses, we also studied the Carat log data of the devices represented in the survey. We found out that the behavior changes over time; there were significant differences between new Carat users, and the more experienced ones.

Since most of the improvement in battery life takes place during the first weeks of using Carat [OIS13], we decided to conduct a follow-up study on new users. In the second part of the study, we focused on how new users form habits. We recruited 10 new Carat users, and studied how they use Carat and what they thought of using it. They were interviewed twice, before they started using Carat, and after one month of Carat use. During the one month period of using Carat, they also wrote in a web diary about their experiences.

In this study, the aim was to find out what features of Carat are most important to users, how Carat affects their behavior, and what the correlation between the reported behavior and the acquired battery savings is. We also studied what are the motivations for the users' behavioral changes, and what strategies the users employ in using the information Carat gives them.

2 Related work

The majority of the research conducted on improving the battery life of mobile devices concentrates on technical aspects of how to make batteries last longer [LSC05, PHZ12], or how to affect energy consumption of software [AmT10, GuS03, SMM08]. There is also some research about applications that give the user advice to prolong the battery life of their devices [DBN13, OIL12, OIS13].

Not much research has been reported on the user behavior concerning the battery life of mobile devices. Of the studies that have been conducted, most seem to focus on users' charging behavior [BRC07, FDK11, RQZ07, RaZ09]. Less focus has been on the actions that users can take to prolong battery life.

The research on behavioral changes in energy awareness is mostly focused on household situations [ASV07, CTG08]. Our research seems to be one of the first ones in the domain of behavior change in energy awareness applications in mobile devices.

2.1 Mobile battery awareness applications

Most mobile devices have some kinds of indicators of the battery level, and possibly also some information on what has drained the battery. In addition to that, there are several applications available for acquiring more information on what consumes energy in mobile devices. Although there are numerous mobile battery awareness applications, not much research has been conducted on them.

One of the early energy awareness tools for mobile phones was a power consumption profiler for S60 3rd edition smartphones [CrK07]. It was not designed for the mobile phone users but its main target was to help mobile application developers to measure power consumption, and by using that information, help them design applications with

low energy consumption. It measured the total power consumption of the device, and created a graph of the results.

There are models that have been created to monitor power consumption, and tools made to support those models, e.g., PowerTutor [ZTQ10], and Sesame [DoZ11]. PowerTutor is an Android application that shows detailed and visualized information about the energy use of the device by different resources, e.g., CPU, WiFi, and the screen, and by applications.

These tools only use information that has been gathered within a specific device. According to our knowledge, Carat is the first energy awareness application for mobile devices that uses a community to gather information, and then uses that information for energy profiling. Without this information it is very hard to find out whether the energy use of an application is abnormally high. With a large community of users, Carat can determine if a certain application is problematic on a single device or on a small group of devices, or if it consumes a lot of energy on the majority of devices.

2.2 Mobile device charging behavior

The work by Rahmati et al. [RQZ07, RaZ09] systematically addressed different aspects of how users deal with limited battery life on mobile phones. The authors studied different strategies regarding charging behavior, and divided the users into two behavioral categories. Type A users charge the phone regularly, regardless of the charge level. Type B users use the information about battery status to decide when to charge their phone. The authors also studied the battery use feedback that the phone gives to the users, and found it inaccurate and inadequate. The power saving settings are also divided between several different screens. All this results in users not thoroughly understanding what drains the batteries. Therefore, a lot of the actions that could be done to prolong battery life are not conducted. However, 80 % of the users have taken some steps to increase battery lifetime according to these studies.

Banerjee et al. [BRC07] have also studied the charging behavior of the users, and used the results to develop a user- and statistics-driven energy management system. They found out that most recharges take place when there is still much of the battery left even when the motivation for charging is the battery level, a lot of the recharges are driven by time of the day or a convenient place for charging, and variations in charging habits are significant.

Ferreira et al. [FDK11] found in their study that there are basically two types of charging habits. People have long charging periods during the night, and shorter periods during the day. They concluded from their more thorough findings that the user's charging habits can reduce the lifetime of the battery.

2.3 Behavior change in energy awareness applications

Feedback for energy conservation has been widely studied during several decades. This research covers work on different domains and disciplines, such as behavioral sciences. Most of the energy-related HCI research is focused on household energy use [PiP12]. Although this domain differs from mobile battery awareness applications, there are also similarities. One of the most important differences is the motivation to save energy: in household environment the main reason for saving energy is usually the wish to save money or the environment, while in mobile devices the main motivation is to make the battery last longer. The key principles mentioned in the literature on the feedback for household settings are also present in Carat, the mobile awareness application we are studying. These principles are: to provide useful and effective feedback, to reward users to keep them motivated, and to avoid information overload.

People behave and think differently for various reasons and constraints, and there is a wide variation within use situations. Therefore the effectiveness of the feedback given can be enhanced by tailoring the given information [ASV07, CTG08]. For the feedback to be efficient it needs to be real-time, and informative in a way that the user will

understand what are the results of his or her actions [MMW83]. The user should clearly understand the desired goal, and what should be done to achieve the goal in the best possible way.

Behavioral changes that have been acquired when people attend an energy efficiency program often diminish rapidly afterwards. However, the longer the duration of the program is, and the more information is given to the users, the longer the effects last. To keep the users motivated, they should also be given clear feedback to tell them whether their actions are effective or not [HHP00]. Riche et al. [RDM10] give three guidelines to support energy saving behavior change: raise awareness, inform complex changes, and maintain sustainable routines. There are many other design guidelines for energy awareness applications such as designing to avoid information overload, or the format of the feedback [FFL10, PFL10, PSP10]. However, in this thesis it is assumed that the ones mentioned above are the most relevant ones in the domain of mobile energy awareness applications.

Most of the energy efficiency tools available only provide feedback after the users have performed actions, e.g., information about previous power use, saved money or carbon footprints [RDM10]. However, there are some recent approaches that concentrate on giving energy consumption information in the form of suggestions [GSC12]. The approach that has been used in Carat is to provide suggestions to the users in addition to information on previous energy consumption.

3 Methods and materials

To understand how people use a mobile battery awareness application, and how it affects their behavior, we conducted user studies during summer and fall 2013. In this research, we studied a mobile energy awareness application called Carat. Previous studies [OIL12, OIS13] have shown that using Carat prolongs the battery life of its users but that research gives very little indication of what has caused the change. The aim of this study is to find out how Carat affects the behavior of its users.

We start by explaining what Carat is, and what information is given to the user via its user interfaces. Then we go into more detail about the research: what are the methods that were used and how the study was conducted.

3.1 Introduction to Carat

Carat [OIL12, OIS13] is an energy awareness application for mobile devices. It is designed to help users manage the battery of their mobile device by displaying information of power use of applications. Unlike many other energy saving applications, it does not use only the information within the device, but collects information from all Carat users worldwide. That way Carat can calculate which applications use more energy than average. Carat also finds out if a certain instance of an application seems to use more energy than the same application on other devices.

The Carat application is widely used; it has been installed on more than 600,000 devices. Carat can be downloaded for free from Apple's App Store for the iOS platform, and from Google's Play Store for the Android platform. This study is conducted with Android users only.

The Carat application on a mobile device sends data of the device's state as *samples* to the server. Each sample includes following information: the user ID of the device, date

and time, battery level, and a list of currently running applications. The server analyzes the data, and compares it with energy use. After the Carat server has received enough samples, it generates reports that include information about the device and the applications it has been using. These reports are sent to the Carat application the next time it is opened.

3.1.1 The main features of Carat

The main purpose of Carat is to give the user information about the applications used on his or her mobile device, and how the most energy draining applications affect the battery life of the device. When a new user starts using Carat, Carat collects samples for about a week before the user receives the first results of the analysis. During this first week, the user should open the device every day, so that Carat can send enough samples to the server. Before the first analysis on that device has been run, the user gets reports based on the list of the running processes on the device, and the analysis conducted within the Carat community. Therefore Carat may be useful to the user even when there is very little data about his or her device in the Carat server.

3.1.1.1 Hogs and bugs

Carat classifies applications by their energy consumption. It has two categories for the problematic applications. These categories are described here shortly. Oliner et al. [OIS13] have described more thoroughly how they are calculated.

Within the Carat community, the applications that use more energy than an average application are called *hogs*. By definition, this means that 50 % of the applications are hogs. An application can be a hog, because it needs to use energy-consuming features of the mobile device to work as intended, e.g., GPS and WiFi. A widely spread misbehavior of an application can also cause it to be a hog.

Applications that are not hogs can have instances that are classified as *bugs*. Bugs are instances of applications that for some reason use more energy than the majority of the instances of that application. E.g., the Kindle application¹ is not a hog. As Oliner et al. [OIS13] reported, some versions, however, used exceptionally high amounts of energy, when used via mobile network. Therefore the application showed as a bug for those users who used their device a lot via mobile network instead of Wi-Fi.

The Carat application has a screen that shows a list of applications that have been classified as bugs on that device. There is also a screen that shows a listing of the applications that have been used on that device, and have been categorized as hogs in the Carat community. These screens (see Figure 1) show the application name, the expected improvement of the active battery life if the application was not used, and the measurement error.



Figure 1: The hog and bug screens [ALK14, Car13]

The user can also look at more detailed information on each of the hog and bug applications (see Figure 2). In addition to the previously shown screens, this information includes the total number of samples within the Carat community where this application was present, and the total number of samples without it. If the user wants to find out what these numbers mean, the explanations can be found on an information screen.

¹ <https://play.google.com/store/apps/details?id=com.amazon.kindle>

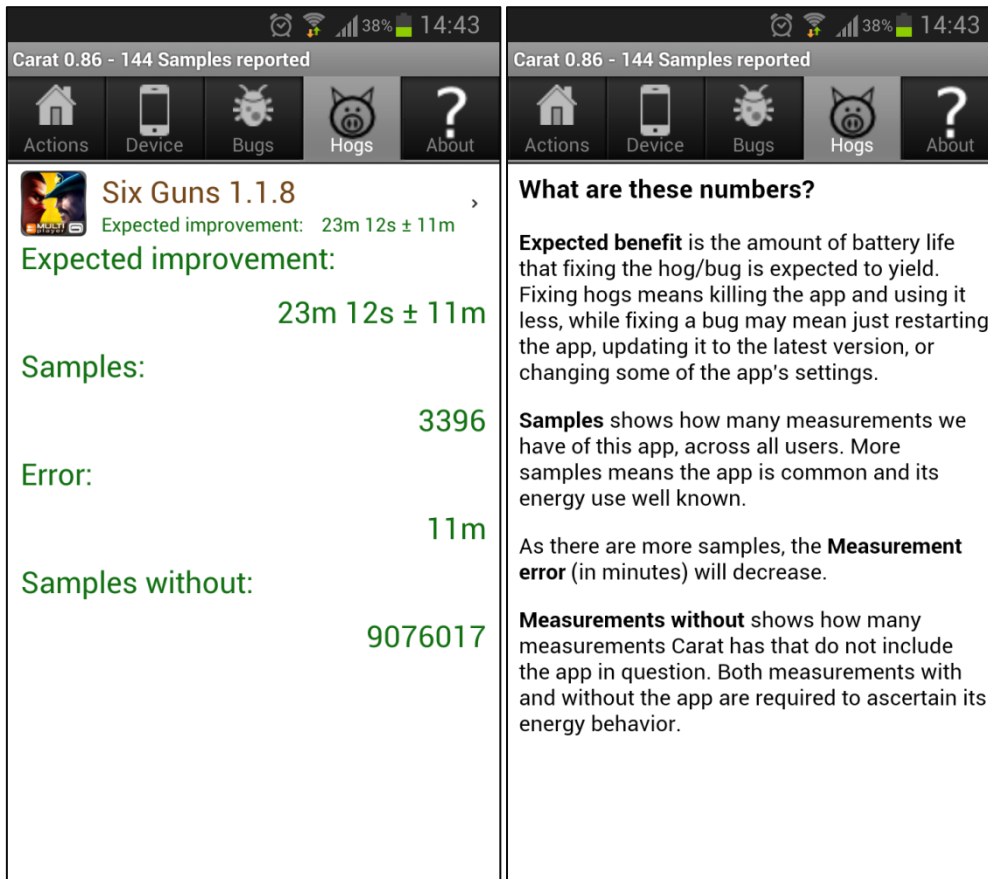


Figure 2: More detailed information of an application [Car13]

3.1.1.2 Actions

When the user opens Carat, the first screen he sees is the “Actions” screen. The suggestions made by Carat are listed on this screen (see Figure 3). The suggestions consist of the hog and bug applications currently running, and the actions Carat suggests that should be taken on them. The suggested action for the hogs is to kill the application, and for bugs to restart it.

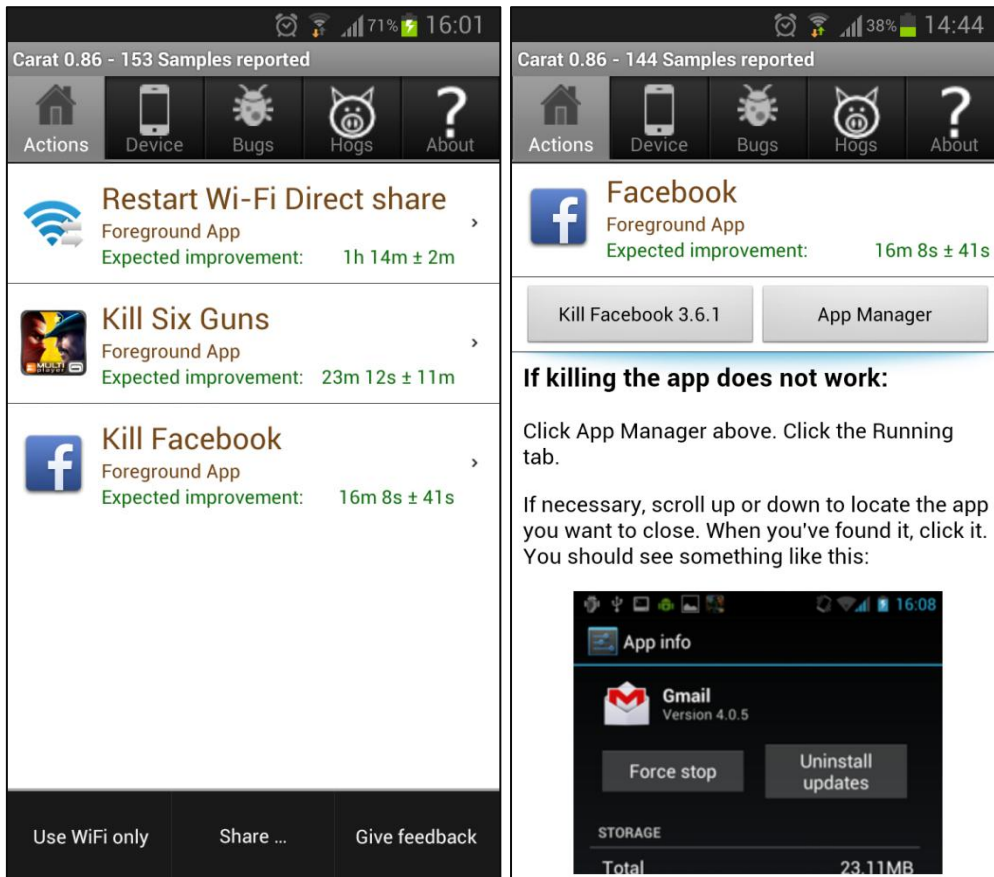


Figure 3: The Actions screen [ALK14, Car13] and the screen where an application can be killed [Car13]

The actions can be carried out within the Carat application (see Figure 3). Sometimes, the application's background service starts right after the application has been killed. In these cases, Carat provides a link to the application manager where the application can be *force killed*. This may cause the application to work unexpectedly, and it may cause problems, especially if the application is part of the operating system.

3.1.1.3 The J-Score and other information about the device

All the previous information concerns individual applications, and not the overall situation of the battery life of that device. On the Device screen (see Figure 4) the user can see other information about the device. On the top of the screen is the J-Score, which tells how the estimated active battery life of this device relates to the Carat community. A high score means that the active battery life of this device is better than on most of the other devices in the community.

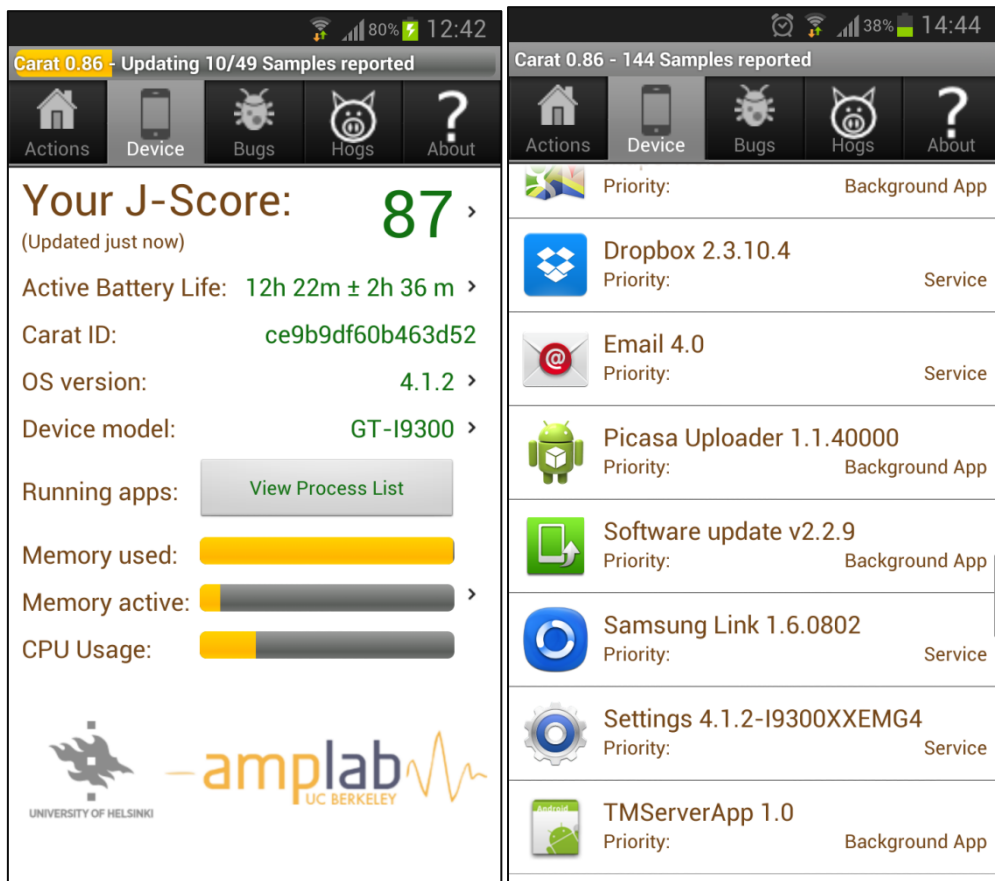


Figure 4: The Device screen [Car13] and a list of currently running applications [ALK14, Car13]

The active battery life tells how long the battery of this device would last if the device was used in a way it has been used previously according to the samples Carat application has gathered and sent to the server. It does not take into account the time the device has been idle, so this number does not tell how long the battery lasts on an average day.

The Carat ID of the device, the operating system version, and the device model are also shown on this screen. A list of currently running applications can be accessed via the “View Process list” button. On the bottom of the screen, the user sees information about memory use on the device. This information can give the user indication of how the applications are affecting the performance of the device.

3.2 Research methods

The research was divided into two parts. First, we conducted a survey on the existing Carat users to get a comprehensive overview of their Carat use. More specifically, we wanted to find out how they use their mobile devices and Carat: their charging habits, what features they use in Carat, and what are their motivations. This data was then combined with the Carat log data of the respondents, to find out what kind of behavior fosters better battery life, and to verify some of their answers.

The first part of the research was conducted collaboratively. The present author designed and implemented the questionnaire to Google Drive after getting comments from other members of the group. Eemil Lagerspetz published the link to the questionnaire, collected the log data, and made the calculations concerning log data. The analysis of the data was for the most part done by Kumaripaba Athukorala and the present author. Eemil Lagerspetz, Antti Jylhä, Adam J. Oliner, Sasu Tarkoma, and Giulio Jacucci also contributed to the analysis. Results of this part of the study have also been reported earlier [ALK14].

The second part of the study involved new Carat users. As the most significant improvement of the battery life takes place within the first weeks of Carat use [OIS13], we wanted to study more closely how new users use Carat. The methods chosen were interviews and web diaries, because we wanted to get a deep and detailed understanding of how the participants would interact with Carat, and what are their feelings and thoughts about it.

Due to the relatively small number of participants in this part of the study, studying their log data statistically would not have made sense. Also, there were no results that could have been verified by the log data. Therefore, we decided not to use the Carat log data of the participants in this part of the study.

The new Carat users recruited for this study were first interviewed about their mobile device using habits and their knowledge about factors that affect battery life. After the initial interview, they started using Carat, and during the study period, they filled in a web diary approximately once a week. At the end of this part of the study, the participants were interviewed again to find out how Carat had affected the way they use their devices. They also submitted their answers to the questionnaire that was introduced in the first part of the study.

3.3 The first part of the study

The first part of the study consisted of a questionnaire that was targeted to all of the existing Carat Android users, and the Carat log data from the users that responded to the questionnaire. This part was carried out with a lot of help from the Carat development team.

3.3.1 User survey

In the first part of the study, we constructed a questionnaire for the existing Carat users. The questionnaire was created using Google Forms, and with the help of Carat developers, we placed a link to the questionnaire onto the “Actions” screen of Carat Android. The link was published for a small portion of the users in the end of June 2013 for a few days, and to all users in August 12th, 2013, and it was open for about two weeks. From the responses, we removed doubles, and as a result, we got 1140 individual responses.

The questionnaire included 16 closed questions, and three free text fields for suggestions for improvement, special thanks, and other feedback. The respondents were asked how long they had been using Carat, on how many devices they used it, their battery charging habits, why they use Carat, what they do when they use it, how do they see their understanding about how Carat works, and how Carat has affected the way

they use their device. They were also asked to fill out some background information. The Carat ID of the device, the device model, and the operating system were automatically added to the questionnaire. The questionnaire that was used is shown in the Appendix 1.

3.3.2 Carat logs

In the questionnaire, we asked the respondents questions about why and how they use Carat. To find out how these different behaviors affect battery life, we decided to study the Carat logs of the respondents. The Carat logs include information sent by the mobile application to the server, *samples*, and information sent from the server to the mobile application, *reports*.

The Carat application collects data from the mobile device in the form of samples. Samples include the user ID, but also snapshots of the state of the device at a certain moment. This snapshot information includes, e.g.:

- Timestamp
- Battery level
- List of running applications.

The Carat server analyses the samples, and compares the data to other devices and applications in the community. Based on this analysis, the Carat server generates reports about the device, and the applications that have been used in it. The reports include, among other things, the following data:

- Average battery life in hours
- The J-Score
- List of applications the user has ever run
- Hogs, and the date they were found
- Bugs, and the date they were found.

These reports are then sent to the corresponding mobile device. The reports, as such, are not shown to the user. Based on these reports, the Carat application generates the information that is shown on different screens.

In this study, we used the log data to quantify the user behavior. The data shows when a hog or a bug was reported to the user, and if the use of that specific application changed after that. The logs were also used to see what kind of behavior and user attributes correlate with better battery life.

3.4 The second part of the study

A field study with new Carat users in Finland was also conducted. This part of the study started with an initial interview, where the participants were asked questions about their mobile device use. After the interview they were asked to write a web diary about their experiences during a one month period. At the end of the study they were interviewed again to find out how they used Carat, and how it affected their mobile device use. Both of the interviews were semi-structured. 14 people participated in the initial interview, and 10 of them took part in the whole study.

Of the 10 participants, most (6) were computer science students, so their technical background was better than average. Of the participants, 6 were women, and the average age was 27 years. One of them used Carat on a tablet, and the other 9 on a mobile phone.

3.4.1 Initial interview

The field study started with an interview with the participants. The participants were asked questions about their mobile devices, their charging habits, opinions about battery life, understanding of what drains the battery, and what they consider important when purchasing a new mobile device. At the end of the survey, the participants were given a short explanation of what Carat does.

3.4.2 Web diaries

In the web diaries, the participants were asked to write what they did when they opened Carat, what they thought of it, and how Carat had affected their behavior. The web diary form that was used is shown in the Appendix 2. The web diaries were made using Google Forms, and each diary entry was one submission. The study lasted four weeks after Carat started providing results, and the participants were asked to submit an entry at least once a week.

3.4.3 Final interview

At the end of the study, the participants were interviewed again. They were asked questions about their experiences and thoughts about Carat, and how it changed the way they used their mobile devices.

3.4.4 Survey questionnaire

After the final interview, the participants were asked to complete the same questionnaire that was used in the first part of the study. Due to the small number of participants in this part of the study, we did not compare these results with the submissions we had received earlier. Instead, we used the answers together with the interviews and the web diary entries to get an understanding of how the new users had modified their behavior, and what were their thoughts about Carat.

4 Results of the first part of the study

In this section, we discuss the results we received in the first part of our research. We outline the statistical analyses of the survey responses and Carat logs. We classify the respondents into two groups, study their behavior, and compare some behavioral aspects with the log data of their application use and battery information. For the open-ended questions in the survey questionnaire, we conducted qualitative analysis.

4.1 Population

We placed a link to the questionnaire on the starting page of Carat for all the Android users. Our goal was to get answers from a wide range of users from different regions of the world. By the time we decided to close the survey, we had gotten a total of 1,140 valid responses.

Of the respondents, only 16 % had been using Carat more than a year, and 40 % less than three months (see Figure 5). The respondents' average age was 37 years, and 89 % of them were male. Most of the respondents (93 %) were answering the survey on their mobile phones, but 26 % of all the respondents used Carat on more than one mobile device. We got answers from over 100 countries in all inhabited continents.

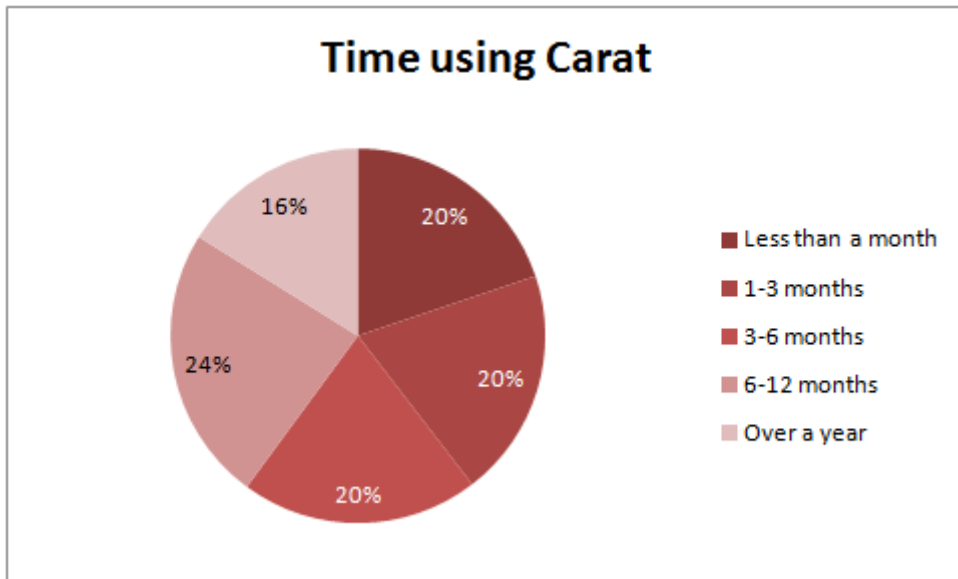


Figure 5: Time using Carat

4.2 Classification of users

The diversity of user behavior in smartphone use is high [FMK10]. Therefore, we studied the characteristics of Carat users to elucidate the features that differentiate them. It has been shown that most of the improvement in battery life takes place during the first weeks of using Carat [OIS13]. Also in this study, we found out that the duration of Carat use correlated with most of the characteristics of Carat users. Hence, we decided to use the duration of use of Carat to classify the respondents of the survey as beginners and advanced users.

As reported earlier [ALK14], there are significant positive correlations between the responses to “*On how many devices do you use Carat?*”, “*How well do you understand how Carat works?*”, and “*How long have you been using Carat?*” The respondents who have been using Carat longer seem to understand it better, and use it on more devices. These results indicate that those who have been using Carat longer have a better understanding of the functionalities of Carat, and have been actively using it.

We compared how the respondents had answered the question “*How long have you been using Carat?*” to the duration of actual Carat use from the Carat log data. We

found out that they are significantly correlated [ALK14]. However, the log data is likely to underestimate the duration of Carat use since it only shows how long Carat has been used on that device, but it is possible that the respondent has used Carat earlier on other devices. Since the log data does not take into account the previous Carat use, we decided to base the classification on the survey responses.

We also needed to define how to divide the respondents into two groups. We first studied the responses to the questions “*How well do you understand how Carat works?*” and “*How long have you been using Carat?*” [ALK14]. We used the reported duration of Carat use as the threshold value, and conducted the Kruskal-Wallis test and the Mann-Whitney U test separately to each of the classifications to find out the correlation to how well the beginners and the advanced users think they understand Carat. The main results of these tests can be found in Table 1.

Definition of beginner	Kruskal-Wallis test		Mann-Whitney U test [ALK14]	
	<i>p</i>	η^2	<i>p</i>	<i>r</i>
< 1 month	$p < .01$	.016	$p < .01$	-.128
< 3 months	$p < .01$	.017	$p < .01$	-.130
< 6 months	$p < .01$	.012	$p < .01$	-.109
< 1 year	$p < .01$	.015	$p < .01$	-.123

Table 1: Results of tests on how the respondents answered the question “How well do you understand how Carat works?”

There is a significant difference ($p < .01$) between beginners and advanced users in all of the classification schemes. However, when the beginners are defined as users who have used Carat for less than three months, and others as advanced users, the difference is the greatest.

There are also behavioral studies on energy awareness applications, where the results have shown that the habits are formed during the first three months, and that those

habits do not change much after that [Dar06]. Also Oliner et al. [OIS13] refer to those who have used Carat for over 90 days as long-term users. Based on previous work and our findings, we decided to use three months as the divider between beginners and advanced users in our study. Table 2 shows the characteristics of these user groups. In the rest of this section we use this classification to analyze different behaviors of the respondents.

Group Characteristics	Beginners	Advanced Users
Number of Respondents	451	689
Duration of Carat Use	< 90 days	> 90 days
Gender	male = 389 female = 60 other = 2	male = 620 female = 58 other = 11
Mean age in years	36	38

Table 2: Primary characteristics of the two groups of respondents [ALK14]

4.3 Reasons for using Carat

We asked the respondents what was for them the most important reason to open Carat. We gave the respondents three options: to be able to use the device longer without recharging, environmental reasons, and curiosity. They were also given a free text field to fill if none of the suggested options was applicable. A summary of the responses can be found in Figure 6.

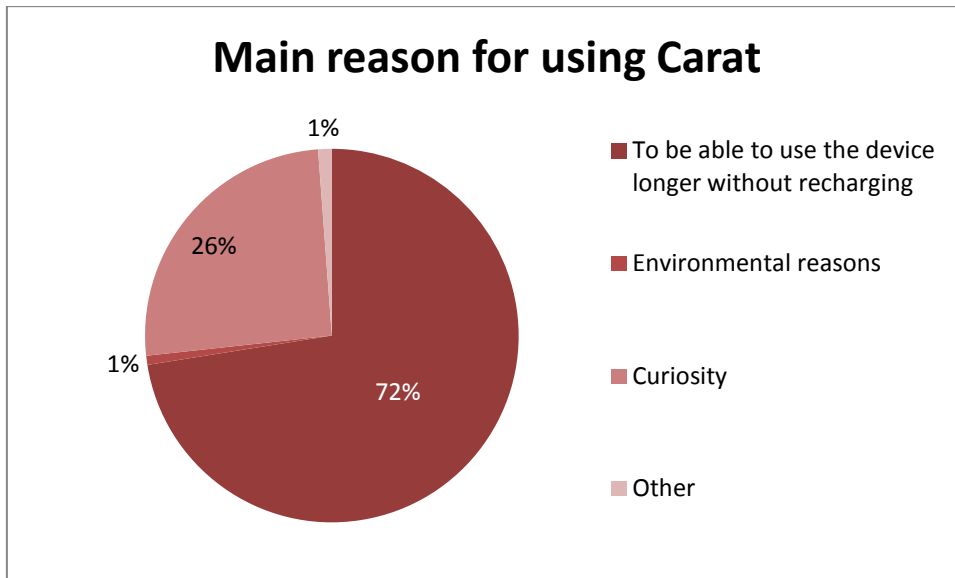


Figure 6: The main reason for using Carat

The most common reason for using Carat was to make the battery last longer (72 % of the respondents). Even though one might think that environmental reasons would be a notable reason for using an energy awareness application also on mobile devices, that did not seem to be the case. Only 1 % of the respondents selected that option. Instead, 26 % of the respondents selected curiosity as the main reason for using Carat. Very few (1 % of the respondents) wanted to give another reason for using Carat. Among the reasons mentioned were, e.g., “*Data analysis*” and “*Comparing if I have a sub par battery*”.

4.4 Reasons for opening Carat

We wanted to find out why the respondents open Carat, and which actions they take with it. First, we asked what is the main reason for them to open Carat. They were given the main features of Carat as options to choose from. A summary of their responses is shown in Figure 7.

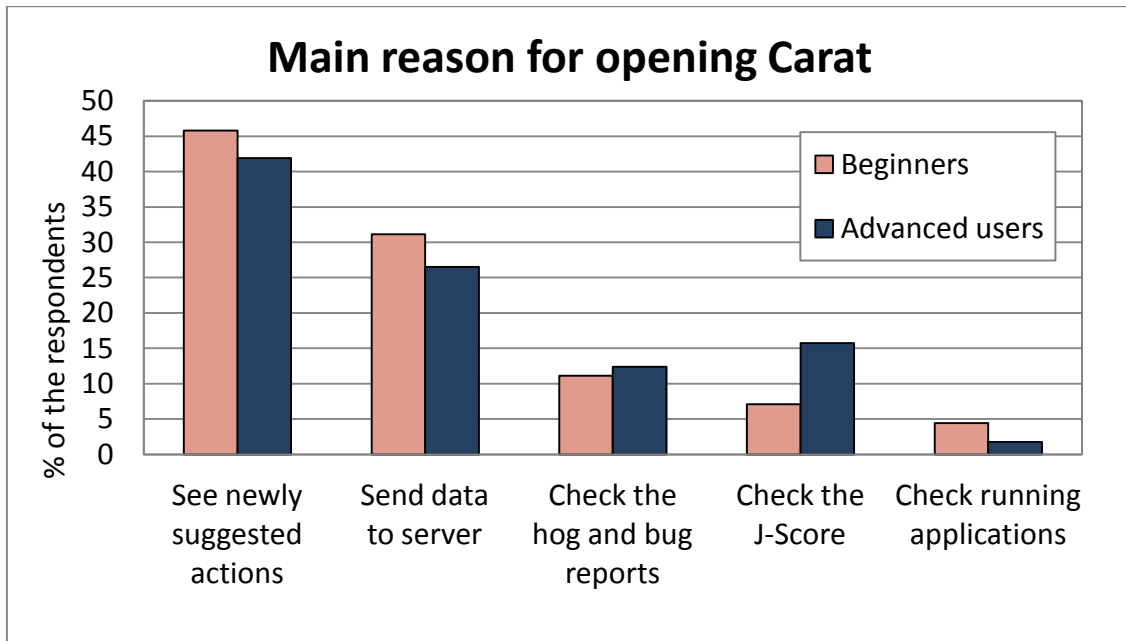


Figure 7: The main reason for opening Carat [ALK14]

We also asked them what actions they take most times they open Carat. They were given a list of actions that can be taken, and they were able to choose as many of them as they considered applicable. A summary of these responses is shown in Figure 8.

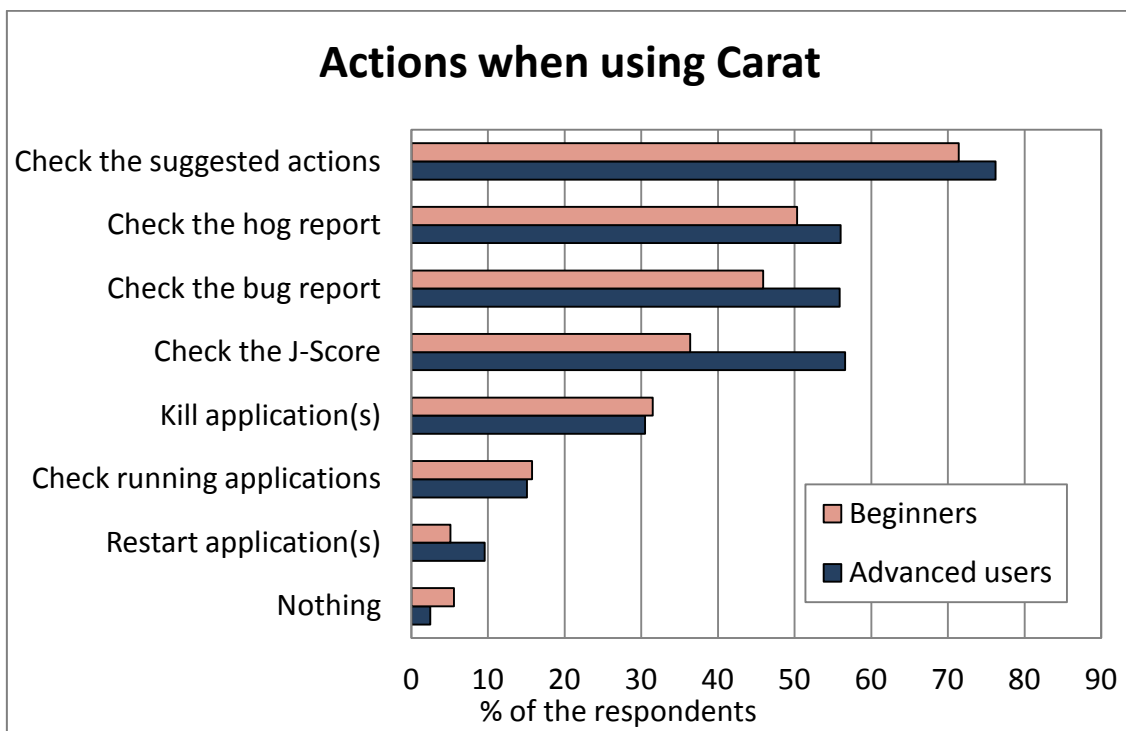


Figure 8: The actions performed when Carat is open [ALK14]

The responses show that checking the suggested actions (killing hogs and restarting bugs) is the main reason for opening Carat for both beginners (46 %) and advanced users (42 %). A great majority of respondents (71 % of the beginners and 76 % of the advanced users) check this information even if it is not their main reason for opening Carat. This was very predictable since this information is on the opening screen of Carat. There are no major differences between beginners and advanced users.

Slightly over 10 % of the respondents (11 % of the beginners and 12 % of the advanced users) selected checking the hog and bug reports as their main reason for opening Carat. About half of the respondents did check these screens, advanced users more often (56 %) than the beginners (48 %). Advanced users check hog and bug reports equally often, but beginners seem to be more interested in hog reports (50 %) than bug reports (46 %).

Part of these differences might be due to beginners not seeing any personalized data at first. Nonetheless, even before Carat has received enough samples to be able to calculate actual results from a given device, it can show a list of problematic applications on the hog report. Bugs, however, are specific to an instance of an application, and therefore there is nothing on the bug report before personalized results have been calculated. This might explain why advanced users are equally interested in hog and bug reports but beginners are more interested in hog reports.

The actions Carat suggests on the opening screen are killing and restarting applications. As killing is suggested for hogs, and restarting for bugs, one might expect to see more restarting applications in the advanced users' group than in the beginners' group but no significant difference in killing applications. That was the case, 31 % of beginners and 30 % of advanced users reported killing applications, and 5 % of beginners and 10 % of advanced users restarting them. The reason why there is more killing than restarting applications is most likely due to the difference between the amounts of hogs and bugs.

Sending data to server was the second most popular reason to open Carat (31 % of the beginners and 26 % of the advanced users). This was more important to beginners, which is probably linked to the fact that new users are instructed to open Carat often, in order to receive results based on applications running on their device. Sending data happens automatically when Carat is opened; therefore it was not an option when asked what the user usually does when using Carat.

Some respondents also stated that they do nothing when they open Carat. This option was selected by 5.5 % of the beginners, and 2.5 % of the advanced users. It is fairly safe to assume that in these cases, the only reason to open Carat would be to send data to server. The fact that this option was more than twice as common in the beginners' group as in the advanced users' group supports this assumption.

The biggest differences between beginners and advanced users were found in checking the J-Score. Of the advanced users, 16 % listed it as the most important reason for opening Carat, and 57 % of them check it usually when they open Carat. For beginners, these numbers were significantly smaller. Only 7 % of them listed it as the main reason for opening Carat, and 36 % of them checked it. The fact that Carat does not show the J-Score before personalized results have been calculated explains only a small part of the difference. It seems that once the user has become more acquainted with Carat and knows what applications are causing problems, the information about those applications starts to lose its attraction. Then competitive and game-like features like the J-Score might start to feel more interesting.

Carat also shows a list of all running applications. It is the main reason for opening Carat for 4 % of the beginners and 2 % of the advanced users. It is usually checked by 16 % of the beginners and 15 % of the advanced users. Carat does not offer any actions that can be taken with these applications, or any information about how much they affect the battery.

4.5 Frequency of opening Carat

In the survey, the respondents were also asked how often they have opened Carat during the previous month. The opening frequency was significantly higher in the beginners' group than in the advanced users' group [ALK14]. A summary of the responses is presented in Figure 9.

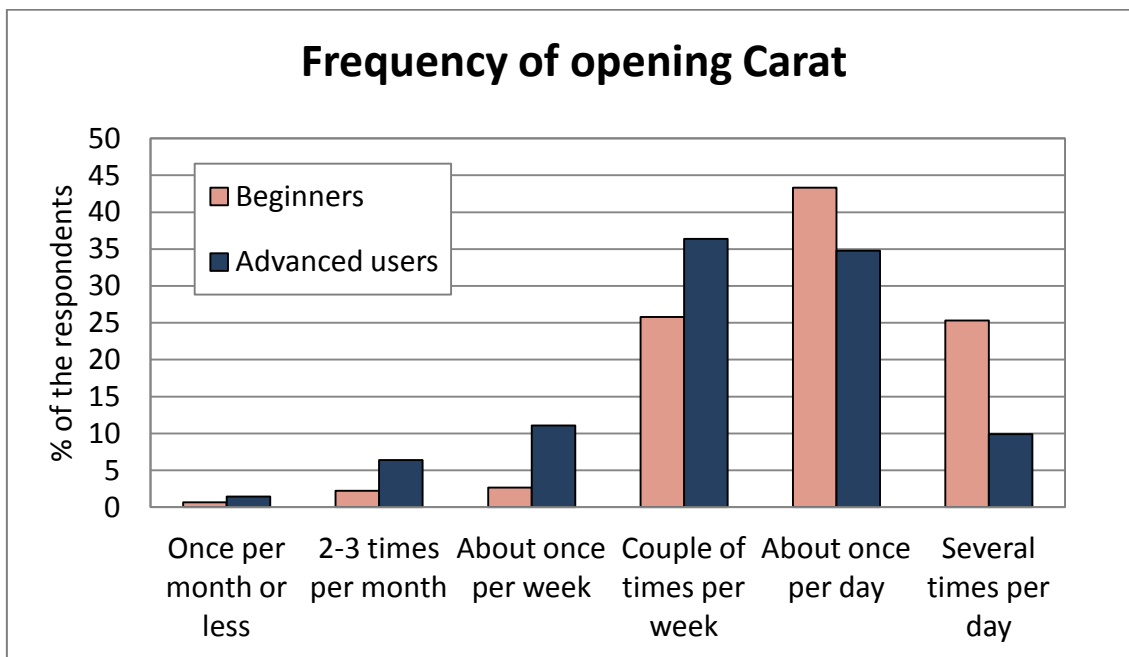


Figure 9: Summary of responses to the survey question “How often have you opened Carat during the past month” [ALK14]

It was quite rare for the advanced users to open Carat more than once a day (10 %) but slightly over 25 % of the beginners did that. Also opening Carat about once a day was more common in the beginners' group (43 %) than in the advanced users' group (35 %). Hence, over two thirds of the beginners open Carat at least once a day but less than half of the advanced users do so. Accordingly, all the other options stating a rarer frequency of opening Carat are more popular among advanced users.

One can find several reasons for these differences. One is that beginners are eager to get new results, and therefore want to send data often, and also check often if there is any new information on any of Carat's screens. Another explanation is that advanced users

already know what Carat would show them, and have learned to manage their battery without much help from Carat [ALK14]. Whatever the reasons are, this shows that the Carat use behavior does change over time.

4.6 Learning to manage the battery

When we made the decision on how to divide the respondents into beginners and advanced users, we compared the duration of use to how well the respondents claimed to understand how Carat works. In Figure 10 one can see how these two groups answered to the question “*How well do you understand how Carat works?*”

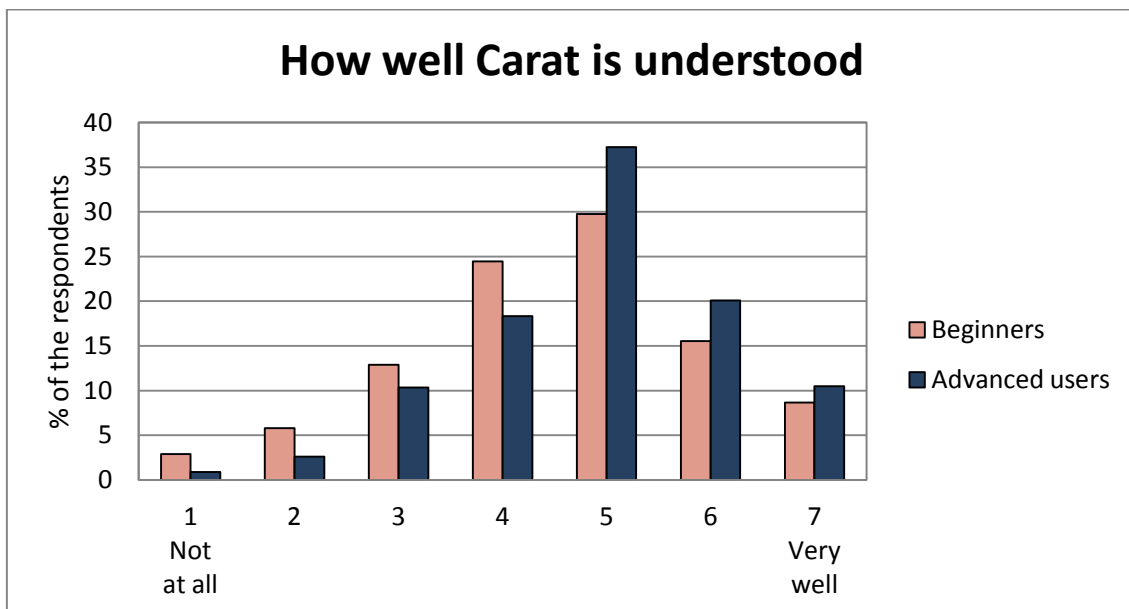


Figure 10: How well Carat is understood

We also tested how the actual battery life improvement shows in these two groups. We found out that there is a significant positive correlation between the duration of Carat use and the percentage of battery life improvement shown in Carat logs [ALK14]. These results indicate that the battery life of advanced Carat users has improved significantly more than that of the beginners. This finding is in line with previous work [OIS13].

We conducted a correlation analysis between the responses to the question “*How well do you understand how Carat works?*” and how often they claim to charge their phone,

and found a significant negative correlation [ALK14]. This result suggests that the respondents with better understanding of how Carat works need to charge their phones less often.

There was also a strong positive correlation between how often the respondents follow Carat's suggestions, and how well they say they understand how Carat works [ALK14]. This indicates that how well the user understands how Carat works has a positive impact on how often the user follows suggestions made by Carat.

It seems that the respondents' behavior changes in time, and it is possible that this change is due to learning to manage the battery better, as understanding Carat better seems to be linked to better battery life. A better understanding of Carat was also linked to following the suggestions made by Carat, but as we see next, there are some problems linked with the suggestions Carat makes.

4.7 Willingness to follow suggestions

Since one of the main features of Carat is to give suggestions about killing and restarting applications, we wanted to study how respondents reacted to them. We asked them how often they follow suggestions, and what are the reasons when they do not.

4.7.1 How often the suggestions are followed

We asked the respondents how often they follow Carat's suggestions of killing or restarting applications. On average, beginners and advanced users seem to follow suggestions equally often [ALK14]. A summary of the responses can be seen in Figure 11.

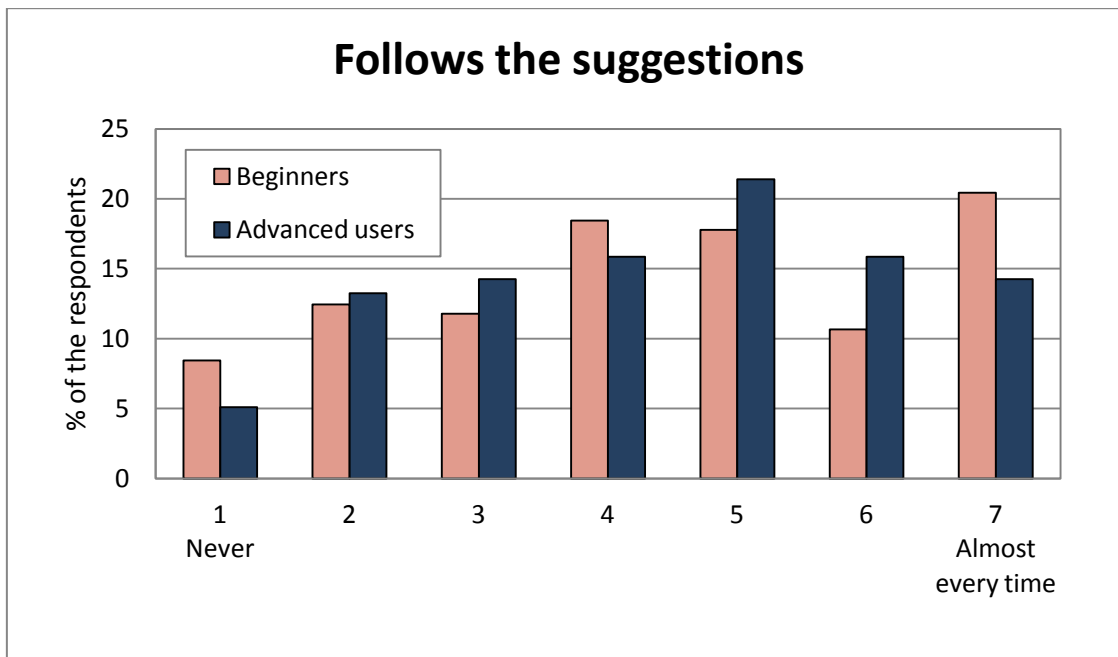


Figure 11: How often the respondents follow suggestions

However, the responses to this question are somewhat different in these two groups. Beginners selected more often “1 Never” or “7 Almost every time” than the advanced user. The most selected option for advanced users was “5”, and over half of them selected a value from “4” to “6”. The variety among beginners and the consistency among advanced users might indicate that advanced users understand the suggestions better, and therefore make better evaluations of when to follow a suggestion and when not to follow one.

4.7.2 The reasons for not following the suggestions

As shown above, the respondents do not always follow the suggestions Carat gives to them. There are various possible reasons for that. To understand these reasons, we considered what these reasons might be, and asked the respondents to pick the ones that they feel are most appropriate. They were also given a possibility to write their own reasons. Figure 12 shows a summary of their answers.

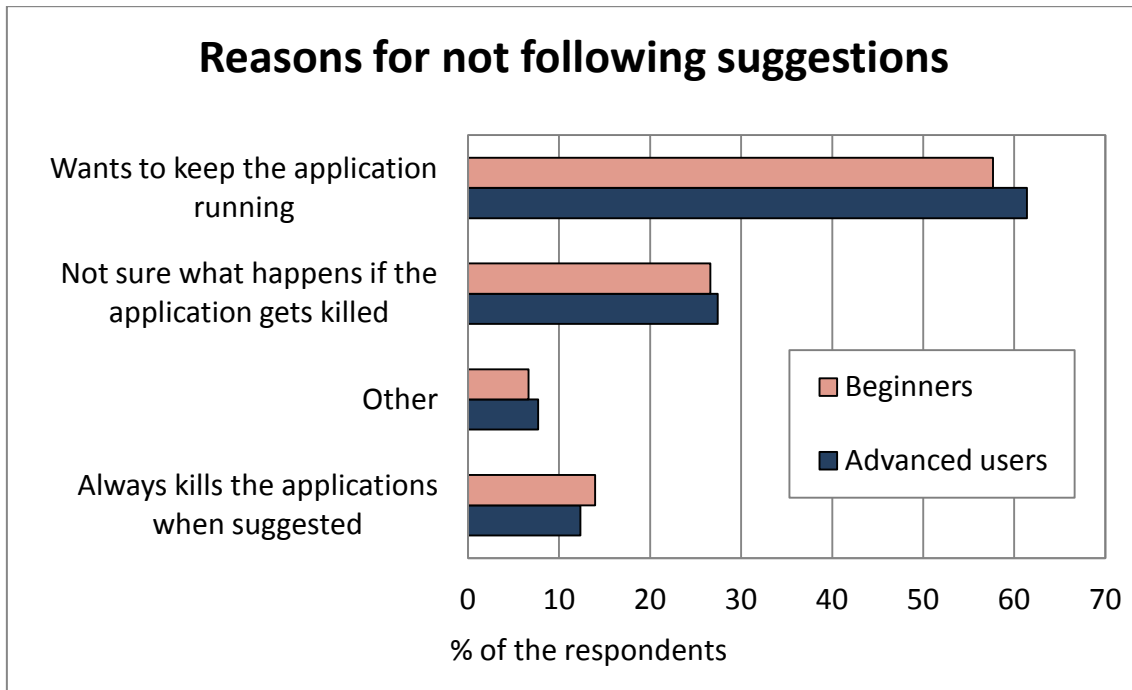


Figure 12: Reasons why the respondents ignore suggestions to kill applications [ALK14]

The majority of respondents (58 % of the beginners and 61 % of the advanced users) stated that they want to keep the application running, even though they are aware that it drains the battery. Many respondents (27 % of the beginners and 28 % of the advanced users) also reported that they do not kill the application because they do not know what would be the consequences of killing an application.

The most frequently mentioned reason in the free-text field “*Other*” was the fact that Carat also suggests killing applications which will restart right after killing them: “*Some of the suggested apps are not killable because they auto restart*”. Many of these applications are system applications that the mobile device needs to have running all the time. The system applications were also mentioned separately as something that should not be killed, and therefore the respondent has not even tried it: “*System app so can't be killed*”.

Some beginners and also one advanced user also mentioned that Carat does not give them any suggestions to follow: “*To the best of my knowledge, I haven't been asked to*

kill an app which, by the way, I'm dying to do.” These respondents had most likely so recently started using Carat that Carat had not yet had enough time to give them any results that could be shown as suggestions. Some respondents, especially in the advanced user group stated that killing applications does not make a very big difference, and therefore they did not bother doing it: “*Estimated battery improvement is minimal.*”

These results show that often Carat suggests actions that the respondent is not willing to take, the potential benefit is very small, or taking those actions would be completely useless. From the user’s perspective, some of the suggestions should not be in the list at all. It also became evident that the information about expected battery savings is useful to the user, who can base the decision on whether to kill an application or not, on that.

4.8 Situations when Carat is opened

In order to understand in what kind of situations the respondents open Carat the most, we gave them a list of possible situations and asked to select the one that best describes their behavior. Figure 13 shows a summary of these responses.

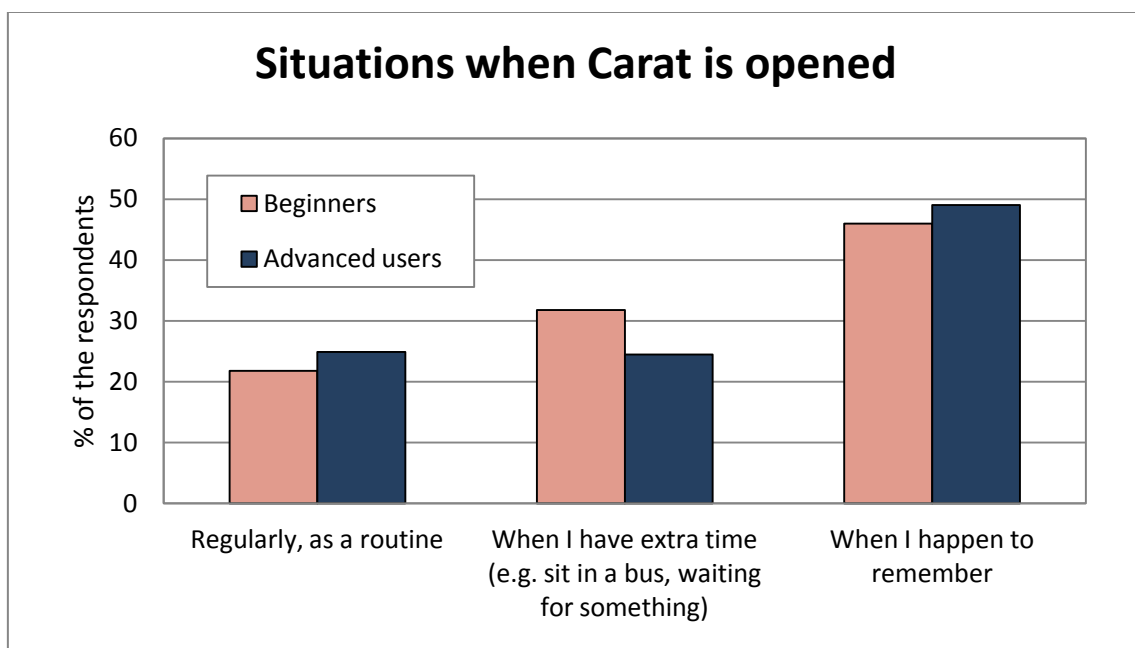


Figure 13: In what kind of situations the respondents open Carat

According to the responses, almost half of the respondents (46 % of the beginners and 49 % of the advanced users) open Carat when they happen to remember, and it is the most common reason for both groups. However, six advanced users said that they have set it to run automatically and another three advanced users stated that they open Carat when there is a specific problem with the battery, or when the phone is slow. We can conclude from these results that the situation in which different types of users open Carat does not vary much across different categories of users.

4.9 Changes in device use

Since using Carat longer improves battery life over time [OIS13] there should be differences between beginners and advanced users on how they use their mobile devices. We asked the respondents what kind of changes in behavior they have detected, and also see whether we can find any differences in the log data.

4.9.1 Reported change

We wanted to know how the respondents view the changes that using Carat has caused them to make. We asked them how they think Carat has changed the way they use their device, and listed the changes we thought would be probable, and also gave the respondent a possibility to write free text. Of all the behavioral change options given, advanced users selected them more often than beginners. Accordingly, beginners selected the option “*It hasn't changed*” more often (29 %) than the advanced users (18 %). Figure 14 illustrates the answers given to this question.

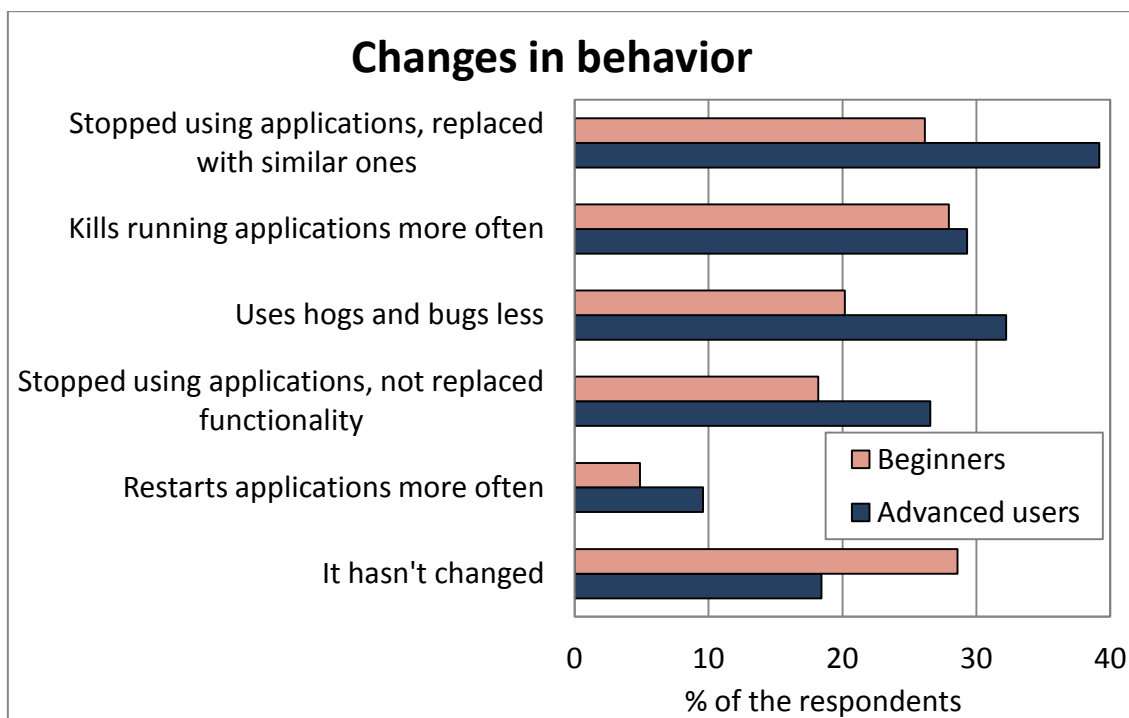


Figure 14: Summary of responses to the question “In what ways using Carat has changed the way you use your mobile phone?” [ALK14]

The two most selected options for advanced users were “I have stopped using some apps and replaced them with similar ones” (39 %) and “I use some apps (hogs and bugs) less” (32 %). For beginners, these numbers were 26 % and 20 %, respectively. The beginners relied mainly on Carat’s suggestions of killing running applications more often (28 % of beginners but also 29 % of advanced users). Since there are less bugs than hogs, restarting applications more often is not very common, but again, advanced users do this more (10 %) than beginners (5 %). Here we have to remember that at first, Carat does not show any bugs while it may suggest killing hogs which may explain part of this difference. The advanced users also selected the option “I have stopped using some apps and I have not replaced their functionality with any other app” significantly more often (27 %) than the beginners (18 %).

Most respondents did not report any other behavioral changes than those that were given to them as options, and there were not many comments on the free text field. One respondent did not stay at the application level: “[I] changed to a custom rom because

of *bugged vendor apps*”, and one respondent stated he does not install applications as carelessly as earlier.

According to these results, advanced users have reported significantly more behavioral changes than beginners. Moreover, the changes advanced users have made, include avoiding using problematic applications more often than the beginners. The beginners rely mostly on suggestions made by Carat. This finding suggests that in time, users learn which applications are not good for the battery, and therefore find ways to use their device more or less without these applications. This might explain why the battery life improves over time the longer the user has been using Carat [OIS13].

4.9.2 Changes according to the log data

The Carat log data gives us, e.g., information of what applications are running when a sample was taken, and when an application was reported to be a hog or a bug. Based on these data, we examined if the information about an application being a hog or a bug affected how much it was used. The calculations about the use reductions are explained in more detail in [ALK14], and a summary of the results is shown in Table 3.

Category	% of hog/bug applications that were reduced	Hogs % reduced	Bugs % reduced	Others % reduced
Beginners	64.3	36.50	23.48	11.51
Advanced users	67.2	46.35	30.12	24.14

Table 3: The percentage of hogs and bugs that the participants reduced the use of, and the reduction percentages, after the first time the participant got a report on them. Part of this table has been published earlier [ALK14].

We found out that both groups reduced the use of problematic applications after they were reported as being hogs or bugs. Beginners reduced the use of 64.3 % of these applications, and advanced users 67.2 % of them. We also calculated how much the use was reduced by studying how much the application was used before it was reported as

being a hog or a bug, and how much it was used after that. The use of hogs was reduced by 36.50 % in the beginners group, and by 46.35 % in the advanced users group. The use of bugs was reduced by 23.48 %, and 30.12 %, respectively.

We also studied if there was a change in other applications than hogs and bugs. We found out that beginners had reduced use of these other applications by 11.51 %, and advanced users by 24.14 %.

Next, we compared these results to find out if there was a significant difference between the two groups. We learned that the advanced users had reduced the use of hogs significantly more than beginners, but the difference was not significant when comparing the reduction of the use of bugs. Advanced users had also reduced the use of other applications than hogs and bugs significantly more than beginners. [ALK14]

These findings back up the results that were acquired in the survey about advanced users reducing the use of problematic applications more than beginners. In addition to using less hogs and bugs, advanced users also seem to cut down the use of all kinds of applications. Even though these applications do not use energy above average, they still use it. When combining these results with the fact that advanced users open Carat less often than beginners, it seems clear that advanced users have learned to manage their battery better, and they do not need much help from Carat to do that.

4.10 The respondents' comments on Carat

The respondents had a possibility to give their comments on what they specifically like about Carat, and what suggestions for improvement they have. Only 20.6 % of the respondents submitted a reply to these questions [ALK14], advanced users more (21.5 %) than beginners (19.3 %). The advanced users gave positive feedback somewhat more (8.6 %) than the beginners (6.4 %), and they gave significantly more suggestions for improvement (18.3 %) than the beginners (8.4 %) (see Figure 15).

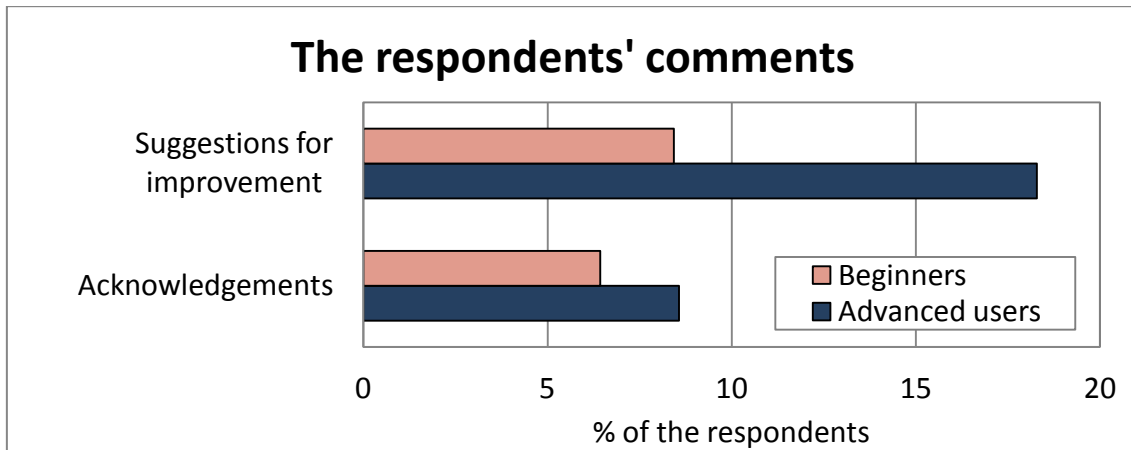


Figure 15: Types of free text comments

4.10.1 The most liked features of Carat

The respondents were asked to specify what are the aspects about Carat that they specifically like. A big portion of the comments did not address any specific features, but many also specified what they liked about Carat (see Figure 16).

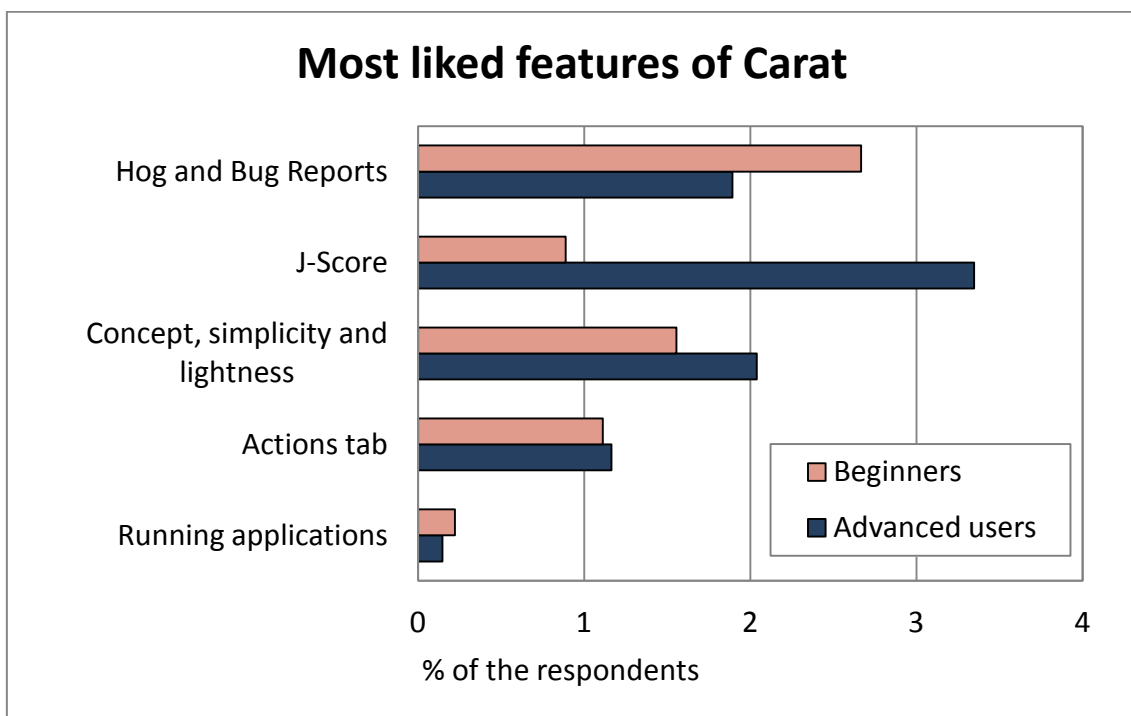


Figure 16: Most liked features of Carat

The hog and bug reports, which can be seen as the main content of Carat, were mentioned often in both beginners' and advanced users' comments, but particularly

important they seemed to be for the beginners. For the beginners, the hog and bug reports were the most liked features of Carat with 2.7 % of them, and among the advanced users, 1.9 % acknowledged the usefulness of these two features: *"I think the best info is the bug or bad behaviour apps. Nice to see what apps are causing problems."*, and *"I find the reports really help me improve battery life."*

For the advanced users, the feature mentioned in the comments most often (3.3 %) was the J-Score: *"The J-Score is a great way for comparing battery life with other devices."* The interest for the J-Score is only a small portion of that among the beginners (0.9 %). Our previous findings about the importance of the J-Score in reasons for opening Carat and in actions taken when Carat is open, are consistent with these results. [ALK14]

The concept of Carat is mentioned in both groups, somewhat more in the group of advanced users (2 %) than the beginners (1.6 %); how it is university based and reliable, it is simple and easy to use, and it does not use much battery itself [ALK14]: *"I feel it is really professional at what it does, it doesn't boast its features but discreetly does the job. I love the fact it has academic origins and doesn't force being memory resident or making me recommend it to friends."*, and *"[Carat] just works without being a hog itself."* The fact that Carat does not kill applications by itself but gives the user the control was also mentioned: *"Thank you for not being a task killer."*

Many respondents liked the fact that the suggestions give a possibility to kill problematic applications within Carat [ALK14]: *"[T]he actions tab had easily accessible information and [the] ability to kill the apps from the tab is a nice touch."* Even applications that did not stay killed gave some respondents relevant information: *"I have found it useful to see which apps/processes are constantly restarted by built-in [...] software."* [ALK14]. Some also mentioned the ability to view all running applications from Carat as a useful feature.

4.10.2 Suggestions for improvement

Advanced users gave more suggestions for improvement than beginners in all topics that came up (see Figure 17). This was expected, since they are more experienced with Carat and therefore know its shortcomings better. The only exception was the hope for different language versions which was present more in beginners' responses. This is understandable since beginners are only learning to use Carat, and it would be easier for them if Carat was available in their own language.

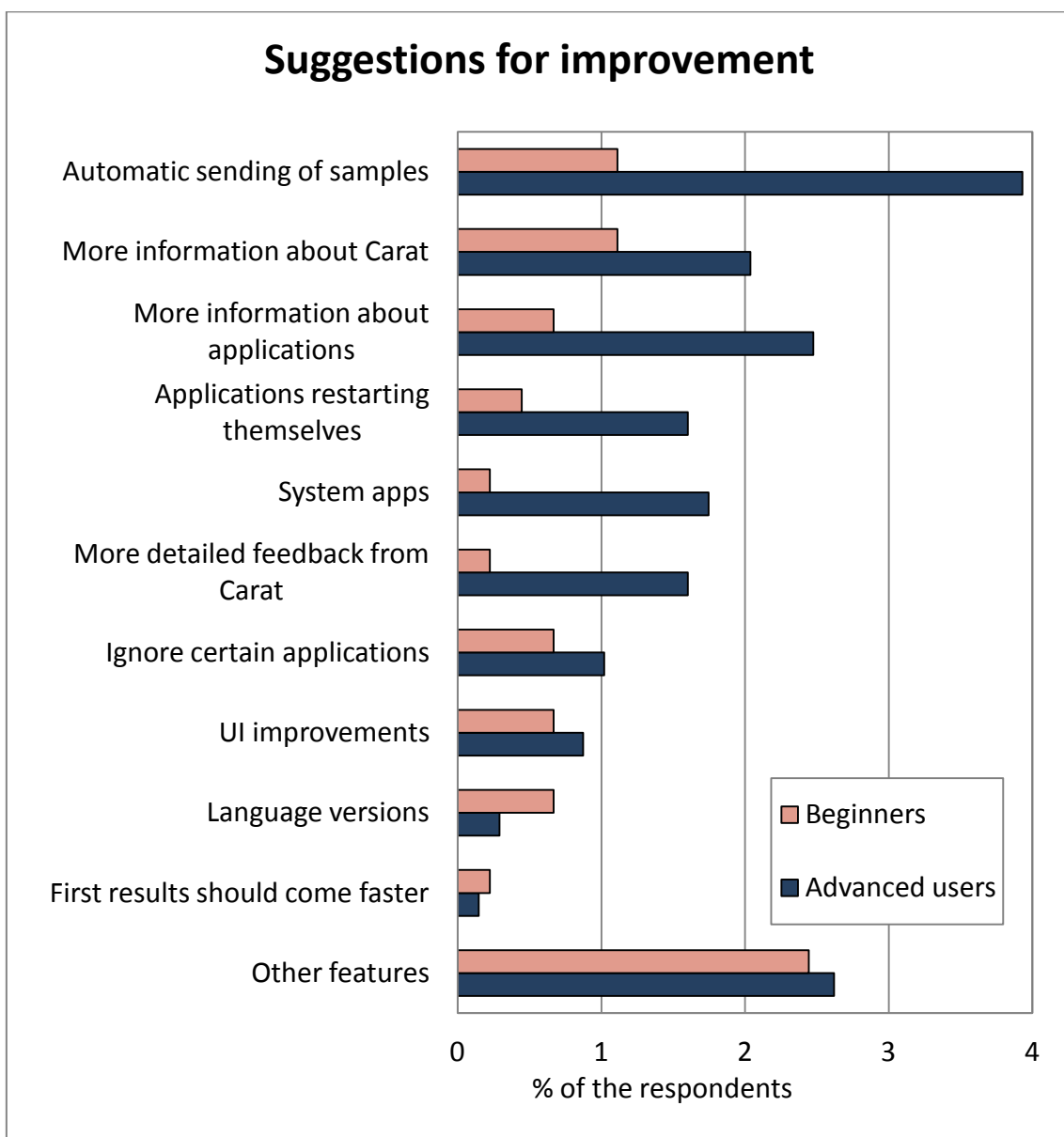


Figure 17: Suggestions for improvement

A topic that repeated in the responses a lot, especially among the advanced users (3.9 %) but also the beginners (1.1 %), was related to the fact that the Carat application only sends samples when it is opened even though it collects samples continually. Some wished for a reminder so that the application would be opened often enough, but most of these comments stated that it would be good to have at least an option to have Carat send samples automatically [ALK14]: *“The app should have a permission setting to allow it to automatically send data to server at a chosen interval (over permitted data connections). Or, take permission to remind to do so sometimes during [the] day.”*

More information or functionality concerning the hog and bug applications was wished for in many comments [ALK14]. In the comments, one could find three types of problems connected mainly to the actions suggested by Carat. First, 0.7 % of the beginners and 2.5 % of the advanced users mentioned needing more information about the problematic application and what it does, before deciding whether they want to kill it or not, or what would be a good replacement application: *“More explanations of what some processes do or what (could) result from killing or restarting.”*, *“It [p]rovides hogs. But no [information] on replacement.”*

Secondly, especially advanced users (1.7 %) pointed out that Carat also shows system applications that should not or cannot be killed, on the suggestion list. Killing these applications can cause problems, as one of the respondents stated: *“Often, [C]arat suggests I should kill vdm client, which from what I understand (and maybe I’m wrong) is a vital [A]ndroid process related to receiving calls or voicemails. Before looking into it, I routinely killed that process and then missed important calls. I understand a user should know what their apps do, but it would be helpful if [C]arat could display what [A]ndroid processes do when it suggests to kill them.”*

A third problem was that for some – system and non-system – applications, killing them within Carat application does not have a real effect, since they reopen shortly

afterwards: *“The apps that Carat suggests I kill [...] just restart themselves instantly.”*

That was pointed out by 0.4 % of the beginners, and 1.6 % of the advanced users. Also, often respondents prefer to have the application open even though it is a hog or a bug: *“There are some apps that use battery, and I know use battery, but that I depend on and will keep using because they're worth it to me.”*

Some comments pointed out the problems, some suggested solutions for them, and some just wished for a specific feature. There were several approaches for the solution. The first one was to give more information about the application to the user, so that he or she can have an informed decision about what he wants to do with it: *“I would like more information of the services that Carat suggests killing [...].”*

Another solution that was suggested particularly for system applications, was to automatically exclude them from the actions list and possibly from the hog and bug reports as well. For the restarting applications some wished for a more powerful killing tool, which would prevent them from restarting. Of the beginners 0.7 %, and 1 % of the advanced users suggested that there should be a possibility to ignore certain applications so that they would not show in the actions list: *“Suggesting that I kill my antivirus [program] seems illogical, some way to add this (or any other app I would like Carat to ignore) as an exception would be useful.”*

Part of the respondents, mainly advanced users, pointed out that there are very different devices using Carat, and therefore comparing (e.g., the J-score) should be done only within similar devices: *“[I] would like to know how my battery compares to others using the same phone in addition to the overall score.”* Also, a deeper view to applications and the analysis done by Carat, were mentioned: *“[I] would like to know how [Carat] calculates the time difference when closing an app.”* These suggestions were made mostly by advanced users, which is logical since they already know what kind of information Carat gives them and wish to deepen their understanding.

A direct wish for information about how Carat works, or comments that implied that the respondent did not actually understand Carat, appeared in both groups. Maybe a bit surprisingly these were more common in the advanced users' group (2 %) than the beginners' group (1.1 %). However, in the beginners' group it was more common to directly say that they do not understand how Carat works, and in the advanced users' group the respondents had more misunderstandings, or they specified more precisely the feature they did not understand: “[I] wish I understood what *expected improvement means*.” [ALK14].

There were some comments about the user interface, hopes for different language versions, and wishes that the first results should come faster. Some individual wishes for specific features were made as well.

5 Results of the second part of the study

In the second part of the study, ten new Carat users were studied to find out how they use their mobile device, how this behavior changed during the study, and how they experience Carat. The analysis for this part of the study was solely qualitative.

The initial interview covered mainly information about how the participants managed their batteries prior to the study. The web diary entries, the final interview, and the survey responses were used to get a comprehensive view on how using Carat had changed the participants' behavior, and what thoughts they had about Carat and battery life management. On average, the participants submitted 5.5 diary entries during the study, and all participants submitted their responses to the questionnaire.

The data from the interviews, web diary submissions, and questionnaire responses were studied carefully, and the comments and insights were recorded on notes. Varied shapes of notes were used to differentiate between sources of data. The notes were categorized, and arranged into groups to create an affinity diagram [BeH98] (see Figure 18).



Figure 18: The affinity diagram

The results of the first interview focused on time before using Carat, so the results on the participants' mobile device use were mostly gathered from that interview. Since all other sources of data had similar information, the results from them are introduced without distinguishing the sources.

5.1 Managing the battery before installing Carat

In the initial interview, the subjects were asked about their mobile device use. Half of them were quite satisfied about how long their battery lasted, and half of them said they had problems with the battery.

However, the opinions on how long the battery should last differed to some extent. One participant stated that the battery on her device lasted 3-4 days, and that was not enough in her opinion. Another participant said that the battery lasts for one day, and that was perfectly sufficient for her. Two participants who liked to use their device and its functions quite a lot said that the battery lasts less than a day in their normal use, which they thought was unacceptable. Most participants whose battery lasted at least a day were at least fairly satisfied with it.

On average, the participants were more or less interested in battery life issues. However, many of them did not actively try to find out more about the subject. If there were no problems with the battery, usually no actions were taken to make the battery last longer:

“I stick my routines as long as battery life is not a problem.”

5.1.1 Using less energy

The participants had developed various solutions to tackle the problem with the battery not lasting long enough. One of the simplest ways was just to use the device less. Often this meant that the participant was not able to do what he or she wanted to, or they used another means to produce the desired outcome, e.g., sent a text message instead of calling someone.

The participants also reported turning off features to save the battery, either when running out of battery, or as part of normal use, trying to prevent problems. Many reported turning off GPS and Wi-Fi, some also Bluetooth and 3G. Three users mentioned occasionally closing applications as a means to save the battery, but none of them considered it very meaningful. One user also reported using an automatic task killer to hibernate applications.

Two participants mentioned having the power saver go on automatically. One of them said that he had set the power saver go on at a higher battery level than what the default of his phone was. One of the actions the power saver usually does is to dim the screen, and one of the participants also reported that he realized from checking the battery status info on his phone that having the screen on uses a lot of energy. Two participants mentioned dimming the screen as one of the ways to save the battery. Additionally, one participant said that she sometimes dims the screen for other reasons, but that she believes that it also saves the battery a little.

The participants were not very satisfied with the results they had gained using these solutions. When asked if they thought these means provided any help with their battery problems, the most common answers were “*maybe*”, “*not much*”, and “*don’t know*”. However, some stated that these solutions work, at least a little.

5.1.2 Making more energy available

All of the previous solutions concentrated on trying to make the device use less energy. Another approach to the problem was trying to make sure there is more energy available when needed. The most common way to do this was to carry a charger, which four of the participants mentioned they do. One participant said that he keeps a solar powered charger with him when he expects to use more energy than he usually does.

Both of the two participants who reported using their phone a lot said they charge their phone as often as possible, especially if they do something they know is particularly power consuming, e.g., listen to music. Two participants stated they only use certain features when the phone can be charged at the same time, e.g., one of them said she uses her phone as a hotspot only in these kinds of situations.

5.2 Advantages of using Carat

We studied the reasons why participants opened Carat and what they did when Carat was open, from the web diary submissions, the final interviews, and the survey questionnaire answers. We tried to find out what motivated the participants to use Carat, and what the experienced advantages of using Carat were. Many of the participants reported this study as the main reason for using Carat which was expected. We got many valuable insights on using Carat in spite of that.

5.2.1 Information about applications

The obvious motivation for using Carat is the information it gives about problematic applications. This information is gained through the suggestions Carat gives, and the hog and bug tabs. One of the participants pointed out that this kind of information about application energy use cannot be found anywhere else.

For one participant, the information Carat gave her about hogs and bugs was not that important since she said she already knew what the problematic applications were: *“I kinda knew that already, oh music and gallery take battery.”* However, this was not the case for other participants. They said they gained new information about their device, and its problems: *“Seems my phone is running all kinds of background programs that are eating the battery life. I thought that Facebook and WhatsApp would be the ‘bad guys’, but it seems like it’s the operating system in itself.”*

The information was also used in order to take actions: *“I look if there's any new information [I] can react to somehow.”* The easiest to use, and probably therefore the most mentioned was the possibility to kill and restart applications within Carat. Many liked the fact that Carat gives concrete suggestions that are easy to follow.

Due to limitations in killing applications via Carat, Application manager was also used to kill applications. One participant, who regularly uses another application to hibernate applications that are not in use, used Carat's information to decide what to add to the list of applications that can be hibernated. Also, one participant used the information about problematic system applications to find out if the operating system on her phone was problematic.

It became evident that if the information did not really change, the participants lost their interest in it: *“It was nice to know in the beginning but as there isn't really anything new anymore and I don't use the information I get I don't find it very useful or interesting anymore.”* Some said that if it was not for the study, they would have discontinued using Carat. It seems that information about applications is not always enough for the users to keep using Carat.

5.2.2 Information about battery duration

Since the purpose of using energy saving applications is to make the battery last longer, the users are likely to be interested in information about their battery life. Carat offers two measurements that give information about how good the battery is. First, Carat shows “Active battery life” which is a measurement that approximates how long the battery would last if the device was used actively from full charge to empty battery. Secondly, the user is shown the “J-Score” which tells how good the device's battery life is compared to other devices using Carat.

Towards the end of this part of the study, these features started to get mentioned more as being interesting. Of course, this is partially based on the fact that Carat does not show this information in the beginning. However, there were statements about Carat not giving any new information about the applications, and that the participants started to look at the active battery life and the J-Score to find out if there had been any changes.

For the most part, the J-Score was used to compare battery duration to other devices, and give context to it: *“A way to compare battery life with measures data that's outside the manufacturers control.”* One participant said that her high J-Score gives her hope since now she understands she is not alone with the problem of the battery running out too fast.

Even though the J-Score does not exactly tell how the battery life on a given device has changed, both of the above mentioned measurements were used to keep track of the changes in the battery life of the user's device. The J-Score was also used as some kind of a competitive game. One participant said that she checks the J-Score every time, and it is a disappointment if it has dropped. She was not very interested in the actual number but more in how it had changed. One participant mentioned the J-Score as the most interesting feature even when it did not change much.

5.3 Challenges in using Carat and suggested improvements

Despite the advantages, the participants encountered various problems. Partially, they were not happy with the way Carat functioned, and partially, they did not understand the information Carat provided. They also had several suggestions about how to make Carat more in their favor.

5.3.1 Waiting to get results

In the beginning, Carat does not give much information about the new user's device. At that point, the fact that Carat shows the increasing number of samples reported

motivated two of the participants: *“The number of samples increases every time :).”* On the other hand, half of the participants started to get more or less frustrated and annoyed since they felt it was taking too long to get results: *“I hope that something (anything!) would happen.”*

It seems that one of the challenges Carat has in getting new users, lies in the sparseness of useful information right after the user has started using Carat, as stated in one of the first web diary entries: *“In the beginning when it doesn't have enough data yet it could provide some overall tips for saving your battery. Or just something to keep the user interested.”*

5.3.2 Problems with suggestions

A lot of frustration was felt with Carat's suggestions. The suggestions were viewed as not useful for various reasons, and the participants also provided suggestions for improvement to tackle these problems.

One of the major complaints was that killing applications in Carat is not effective; many of the applications kept restarting right after killing: *“It would be nice if the killing of the apps would actually work.”* Almost all of the participants reported this as a problem. Some of the applications that kept restarting were system applications but not all of them. For example, the Facebook application² was mentioned several times.

Nine participants also stated that one of the reasons they did not follow suggestions was that they needed or wanted to have the functionality the problematic application provided. Sometimes, the expected battery improvement was not enough to make the participant feel it would make any real difference to kill the application. One participant

² <https://play.google.com/store/apps/details?id=com.facebook.katana>

also pointed out that one of the suggestions he got was a system application that was vital for receiving phone calls, and therefore it should not be in the list at all.

As the suggestions list consisted mostly of suggestions that the participants perceived as not useful, they started to get annoyed seeing the same applications on the suggestions list when they had no intentions to take actions on them. Being able to prevent selected applications from showing on the list was presented as a solution that would reduce the irritation caused by these suggestions: *“It would be nice if you could hide some suggestions. Like I want to keep Facebook running so it's pointless to see it all the time on the list.”* This solution was seen as the best option for applications that the participant needs, e.g., alarm, even if it is a hog or a bug.

However, this does not help to save the battery. Especially when the problem was the fact that applications kept restarting, the participants wished for a solution that would make the applications stay closed: *“However, I do think that it has some annoying behaviour: [...] not being able to find out how to permanently disable some apps.”* One participant wanted to have a hibernate function within Carat but also said this might be problematic since the user would need to have root privileges. Another participant wished for the ability to integrate Carat with an automated task killer.

5.3.3 Lack of automation

Four participants mentioned that Carat's ease of use would increase if automation was added to some of its functions. At the moment Carat needs to be opened manually to have it send samples and to see suggestions, and the suggested actions need to be taken manually as well.

Having to open Carat manually seemed to be a problem: *“I found it a bit hard to remember to open it daily in the beginning, but then I placed the icon on my home screen.”* This was the case especially in the beginning, because the only reason to open

Carat was to send samples to the server, and there was no real information to the user yet. In addition to not remembering to open Carat, opening it manually was mentioned as being just inconvenient: *“It would be much user friendlier if the app would run scheduled in background, and started perhaps twice a day or so.”*

Killing applications within Carat was viewed as one of Carat’s core functionalities. However, three participants thought it would be good if there was some automation attached to it. The level of desired automation varied from having Carat kill certain applications when it is opened, or having Carat give notifications when it discovers there are energy-consuming applications running, to automatically scanning and killing applications: *“It would be convenient to let the same application that detects the battery eating behaviour to handle the ‘not letting to run’ part as well.”*

5.3.4 Problems in understanding Carat

Another problem that was present in many comments was that the participant did not understand the information Carat gave, or did not know what to do with it. Some of the participants stated directly that they did not understand something, or it became evident in their comments that they had misunderstood information or a feature.

Many of these problems concerned Carat’s suggestions. Especially the participants with little or no technical background were puzzled with applications they did not recognize; usually these were system applications. They did not know what would happen if these applications were killed, and if they did kill them, often the applications restarted immediately. However, even when most participants experienced this behavior as annoying, one of the participants interpreted it as an indication that it is safe to kill any application: *“[...] I got the idea that if the app really needs to be running it will open itself again.”*

The problems were more evident when the participant was unfamiliar with the application that was suggested to be killed but the problems were not limited to them. The participants mentioned not understanding why some applications kept restarting, why some applications were on the suggestions list, what does killing an application mean, and what would be the consequences if it was killed. It also seemed to be problematic that Carat may show applications on the suggestions list that do not show in the running applications list in Android settings: *“I decided to try and kill [the application], but since it did not work through Carat I attempted to find it in the running applications and could not find it. The front screen of Carat still tells me to kill it.”*

The relationship between the suggestions and the hog and bug listings was not always clear. On the suggestions list are only shown the hogs and bugs that are running at that moment, while the hog and bug listings show all problematic applications that Carat has detected running on that device at some point. Yet, three participants wondered why all the hogs and bugs do not show in suggestions, or hoped for features that do not make sense if you understand this difference: *“I would like to see a ‘Restart this app’ button in the bugs, because I don't know how to restart them.”*

Generally, most participants hoped to have more detailed information about Carat's features. There were statements about not understanding what “Active battery life” means, and that the number shown there does not make any sense, and what does it mean that the “Memory used” seems to be always almost full.

5.3.5 Additional improvements

As shown above, many participants had problems understanding how Carat works. There were also a number of comments stating Carat should give more information about how different measures are calculated, and what is the reasoning behind them: *“[I] don't quite trust the program, without knowing exactly how it works.”* A very

common wish was to see more visible and, especially, more understandable information. Four participants mentioned that only technically oriented users would be able to understand and use Carat successfully. In order to make Carat safer to use, one participant hoped that Carat would be more cautious with applications that are critical for the device to perform properly. Carat should prevent killing these applications, or at least warn the user about the consequences of killing them.

In addition to having more information about how Carat works, half of the participants wanted to see more of the data Carat collects and calculates: *“It would be nice if there was some statistics or a summary page for information that you have gathered concerning the programs. This is information that you probably already have in your databases.”* There were also hopes to see visualizations of the collected data, and how different measures had changed during time: *“[I]t would be nice to see some long term statistics so I could see if anything has changed with how I use my phone.”*

Half of the participants wished to see information in much more detail: *“Some sort of summary of what applications have used how much energy so far. Preferably so that I could look at energy consumption for a specific date, a specific hour, a week, a month and so on. Just not suggestions on what to close, but a proper summary on what has used energy, how much and when.”* Three participants also wished to see information that Carat does not have, e.g., which things cause the application to drain the battery and what could be done for it to use less energy, what the application does, and what would be a suitable replacement for it.

Since there are several factors affecting the battery life of a mobile device, two participants would have liked to see a more comprehensive view of what is using the energy. That way the user would have better chances of getting the battery last longer: *“Carat could also monitor the brightness of the screen, and if, e.g., Bluetooth or Wi-Fi are on unnecessarily.”*

5.4 Behavioral changes

Most of the participants reported some behavioral changes. Maybe the most obvious one was that they said they kill applications more often than what they used to do. Three participants said that they have done this because they have now realized that closing applications affects battery life. Partially, they use Carat to do this, but they also mentioned killing applications in the task manager, and that they kill also other applications than hogs and bugs.

Overall awareness of how applications affect battery life has caused half of the participants to limit the use of applications. In addition to killing applications more often, two participants mentioned they have simply started to use them less. One participant said that he uses an energy saving application that can hibernate other applications, and that he has started to add hogs and bugs to its list of applications that can be hibernated.

Most participants mentioned that they have started to think more about what applications they want to have installed in their device. One participant said that she has uninstalled a number of applications she did not use, and that she had not really done that before. Another participant said that she has uninstalled all the hogs and bugs she did not find valuable. Also, one participant mentioned getting more critical towards installing new applications. She said she thinks more whether she really needs the application. On the other hand, two participants said they are not so concerned about installing new applications as Carat would tell them if they are problematic or not. One participant also mentioned replacing a problematic application with another one.

Using Carat has also caused somewhat unexpected consequences. One participant mentioned that just the fact that he uses Carat, has made him think about the battery more than usual, and this has made him charge his device more than earlier. Another

participant stated that she has started to think about changing the operating system since many of the problematic applications on her device seem to be system applications.

5.5 Comparing the findings to earlier results

Since the aim of the second part of the study was to deepen the understanding of the results found in the first part, it was not a surprise that many of the findings of this part confirmed our earlier findings. In addition to that, we were also able to deepen our understanding in some aspects.

We discovered various ways how the participants managed their batteries prior to the study. In addition to charging the device more and just using it less, they mainly turned off certain features of the device to save the battery. Generally, they did not feel their attempts in trying to save energy were very beneficial.

Before this study, most participants did not think about their use of applications as a way to manage the battery. However, by the end of the study, most participants reported killing applications more, using existing applications less, uninstalling applications more often, or being more critical about installing new applications. As most of them did not pay much attention to their application use before starting to use Carat, this was a significant change in their behavior. The participants' overall awareness about applications using energy definitely increased.

We also received comments that some participants would have discontinued the use of Carat if they did not participate in the study. The reason for this was usually the lack of interesting or useful information. It became evident that in order to keep users using Carat, it is important to constantly give them information they find valuable. What this information is varies among users. Therefore, it is important to provide many types of useful information.

Even though most participants had a technological background, a significant part of them reported not understanding properly how Carat works, or it was evident that they misunderstood something. This issue also came up during the first part of the study but it was especially clear when studying new users. It caused confusion and frustration, and also made some participants more likely to stop using Carat. Therefore, unclear and unambiguous information does not only make it harder to achieve good results in battery management but also decreases the likelihood of users sticking with Carat.

6 Limitations

An obvious limitation of this study lies in self-reporting. The participants may not remember things correctly, they might exaggerate things, and they might give just one side of the story. For much of the self-reported data collected in this study, there is not a reasonable way to verify it. However, we have compared self-reported data to Carat logs in situations where it was possible. For other parts, we have assumed that the reported data is not too biased, and it will not significantly compromise our results.

In the first part of the study, the survey was published on the opening screen of Carat on all Android devices. For most of the population it was available for two weeks. This might have excluded some users who open Carat less regularly. Also, although the survey was open to all Carat Android users, the ones who submitted a response might not be a representative sample of the whole population. Again, we assume this does not affect our results too much.

We have used the duration of Carat use as an explanatory factor for our results. It is possible, that some or most of the results have been influenced by other external factors, such as long-term experience with mobile devices. However, it has been shown in previous studies [OIS13] that the duration of Carat use is linked with improved battery life, and that improvement is greater if the user receives suggestions. Long-term use of energy awareness applications has also been shown to make users form habits [Dar06]. Therefore, we think it is safe to assume that the duration of Carat use is the most relevant factor when studying the reasons for behavioral changes.

In the second part of the study, new users were recruited via university e-mail lists, and most of the participants were computer science students. The number of participants was relatively small. We are aware of the fact that this makes our sample not representative of all possible Carat users. Also, they are not necessarily people who

would have installed Carat if they did not participate in the study. Thus, we might not get a comprehensive understanding of how new users adapt to using Carat. However, many of our findings confirmed the results we had achieved during the first part of the study, and we assume we would have gotten similar results also with another sample.

The new Carat users were also aware that they were participating in a study, which may have caused them to act in a different way that they would otherwise have: *“I’d like to react to all the items on the hogs tab, but for the sake of this test, I’ll just see how things develop.”* Since our goal in this study was not to obtain exact, measurable results on battery life improvement but to find out different types of behaviors connected to the use of Carat we believe our findings gave us the understanding we were aiming to get.

7 Conclusions

We conducted a user study on an energy awareness application called Carat. The study was carried out in two phases. In the first part of the study, we conducted a user survey, and studied the Carat log data of the devices represented in the survey. In the second part of the study, we studied how ten new Carat users used Carat and what they thought of using it.

The fact that the long-term use of Carat results in better battery life [OIL12, OIS13] even though the advanced users open Carat less often than beginners, indicates that Carat has helped the users learn to manage their battery better. In this research, the aim was to understand better how and why users use Carat, and how using Carat has affected their behavior.

Our findings can be classified into two groups. First, we discuss what aspects affect learning in energy awareness applications, what kind of information should be given to the users, how it should be presented, and what is the role of feedback. Secondly, we consider which aspects help to keep the users interested in using an energy awareness application for a long time. This is especially important for applications like Carat that rely on gathering data from a large user base.

7.1 The information given to users

To foster learning in energy awareness applications, it is important to provide the user information that is both thorough enough, and easy to understand. Although Carat users apparently learned to manage their devices in the course of time [OIL12, OIS13], Carat seemed to have some challenges in both of these aspects. There might have been even better results in battery life if the information was more suitable for the users' needs.

7.1.1 Comprehensive information

Carat gives users information mainly in three different ways: suggestions, hog and bug listings, and battery life indicators (Active battery life and the J-Score). The first two give most of the information the user needs to diminish battery drainage. Carat tells the user what applications are problematic, and gives concrete suggestions on how the user should act on them.

However, the users are not always willing to follow suggestions if they do not know the reasoning behind them. Moreover, often the suggestions do not work, or the user is unsure what would happen if he or she followed the suggestions. In these cases, the user would need more information about why this happens, if anything can be done with the situation, and what are the alternative ways in which the problem could be solved.

When the purpose of an application is to help users gain understanding about what factors affect battery life, it is important to present enough useful information to the user. If the user does not understand the reasoning and the data behind the suggestions, the possible behavioral changes are more likely based on chance than actual learning. From the responses, it became evident that the users craved for more information than what was presented to them.

To serve the purpose of making the battery last longer, Carat gives the user information about problematic applications. However, they are not the only things causing the battery to drain. The users are also interested in other ways to learn to manage their batteries. Therefore, an application that gives the users information also on other possibilities to manage the battery would most likely fulfill the needs of the users better.

7.1.2 Unambiguous information

Just as the application needs to show enough information to the user, the information also needs to be clear and unambiguous for the user to understand it correctly.

According to our findings, this was not always the case with Carat. Many of the participants reported not understanding what, e.g., active battery life or killing an application means, and some had also misinterpreted some of the information Carat presented to them.

When an application is used widely, as is the case with Carat, the background and technical understanding of the users vary greatly. Some of the participants stated that one needs to be technically oriented to be able to understand how Carat works. This causes a large portion of the users to struggle in understanding how to manage their batteries. Clearer information would most likely enhance the results for many Carat users.

7.1.3 System applications

A special case of applications that were mentioned often in the study were system applications. For the most part, they could not be killed, or if it was possible, killing them caused severe problems. At the moment, Carat maintains a list of known system applications, and these do not show in suggestions, and hog and bug listings. However, this list seems to be far from being exhaustive. As this is the case, Carat should take into account that some system applications do show in these listings. Moreover, information about problematic system applications can also be valuable to the users.

It might be worth reconsidering how system applications are handled in Carat. The results of this study indicate that the users could be given more freedom to decide how they want to see system applications, and that they should be given a possibility to mark non-listed applications as system applications. It is also possible to start using the Carat user community to help maintain the list of system applications. In any case, system applications seem to require special treatment.

7.1.4 Feedback

Carat gives feedback mainly in the form of battery life indicators, i.e., estimated active battery life and the J-Score. At the moment, Carat only presents the current states of these measures. However, these values change relatively slowly. Therefore, the user needs to memorize earlier values to notice any possible changes in battery life. Presumably because of this, many participants wished for visualizations to see how these measures had changed over time.

Giving effective feedback about energy consumption is rare, and visualizations are likely to help in making the feedback more useful [RoB11]. Since the main reason for people to use energy awareness applications is to be able to use the device longer without recharging, the kind of feedback that tells them if they have been successful in this sense is likely to be effective. The estimated active battery life and the J-Score both provide useful information. However, adding the time perspective in the feedback would make it significantly easier to notice changes, and learn from them.

7.2 Keeping the users interested

The results Carat gives rely heavily on getting data from a large amount of users. Therefore, to keep the user base large enough, it is important to keep the application tempting to all kinds of users. The users' needs change over time, and therefore the provided information should adapt to different situations. At first, the users are most interested in learning new things about their device, and how various applications affect battery life. As they start to understand these things, other aspects begin to feel more appealing.

New users are anxious to get any useful information from the application. They are not very willing to wait several days for something to show up, which often happens with

Carat. This is something Carat could improve in order to retain new users long enough to start receiving personalized results.

Once the users have started to understand how to change their behavior concerning applications, and in that way learned how to manage their batteries, there needs to be something else to keep them interested. The active battery life can serve this purpose by giving the user a concrete measurement that he or she can try to make better. The J-Score is also used for this purpose, even though it does not directly tell how the battery in a specific device is performing. However, it is only two digits, whereas the battery life is shown as total hours and minutes together with the error range of hours and minutes. This makes the J-Score faster and easier to perceive and remember.

However, a more interesting aspect with the J-Score seems to be the possibility to compare battery performance to other devices. There is also a competitive and playful aspect attached to it, which seems to attract especially the long-term users. As the J-Score was the most important feature for the participants that had been using Carat for a long period of time, these aspects could even get a bigger role in developing these types of applications.

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Appendix 1: Carat usage questionnaire

Carat Usage

Please help us improve Carat by answering these questions about your Carat usage. Answering will take approximately 5-10 minutes. Thank you!

Basic information about the mobile device and using Carat

How long have you been using Carat? *

If you have used Carat on other devices than this, include here also that usage.

- Less than a month
- 1-3 months
- 3-6 months
- 6-12 months
- Over a year

What kind of device are you using now? *

- Mobile phone
- Tablet
- Other:

Do you use external batteries for this device? *

- Yes
- No

How often do you charge the battery on this device? *

- More than once per day
- Once per day
- 4-6 times per week
- 1-3 times per week
- Less than once per week

On how many devices do you use Carat? *

- Only this one
- 2
- 3
- 4
- 5 or more

Using Carat

What is your main reason for using Carat? *

- To be able to use the device longer without recharging
- Environmental reasons
- Curiosity
- Other:

Why did you choose Carat (instead of some other energy saving app)? *

- It seemed to be the best one
- It was the only one I knew of
- I just picked one
- I use others as well
- Other:

How well do you understand how Carat works? *

1 2 3 4 5 6 7

Not at all Very well

Are you interested in knowing how Carat works? *

1 2 3 4 5 6 7

Not interested Highly interested

What is the main reason for opening the Carat app? *

- Send data to server
- To see if actions are suggested (killing or restarting apps)
- Look at the reports
- Check the J-Score
- Check running apps
- Other:

Which of the following things do you do most times when you open Carat? *

- Check the suggested actions (killing or restarting apps)
- Kill app(s)
- Restart app(s)
- Check the bug report
- Check the hog report
- Check the J-Score

- Check running apps
- Nothing
- Other:

How often do you kill or restart an app when Carat suggests it? *

1 2 3 4 5 6 7

Never Almost every time

What are the reasons why you don't kill an app when Carat suggests it? *

- I want to keep it running
- I'm not sure what happens if I kill it
- I always kill the apps when suggested
- Other:

How often have you opened Carat during the past month? *

- Several times per day
- About once per day
- Couple of times per week
- About once per week
- 2-3 times per month
- Once per month or less

In what kind of situation do you usually open Carat? *

- Regularly, as a routine
- When I have extra time (e.g. sit in a bus, waiting for something)
- When I happen to remember
- When I'm with someone I want to share the information with
- Other:

In what ways has using Carat changed the way you use your device? *

- I have stopped using some apps and replaced them with similar ones
- I have stopped using some apps and I have not replaced their functionality with any other app
- I kill running apps more often
- I restart apps more often
- I use some apps (hogs and bugs) less
- It hasn't changed
- Other:

Suggestions for improvement

Would you like to have other features, Should the existing features work better, etc.?

Special thanks

What works great, what is the feature you really like, etc.?

Other feedback**Background information**

This is used for statistical reasons only and will not be given out to other purposes.

Your age in years *

Sex *

Female

Male

Other:

The country where you live at the moment *

Information provided by your device

Please do not modify this information.

Carat ID *

Device Model *

Device OS *

7. How well you understand why Carat suggests you something?

1 2 3 4 5 6 7

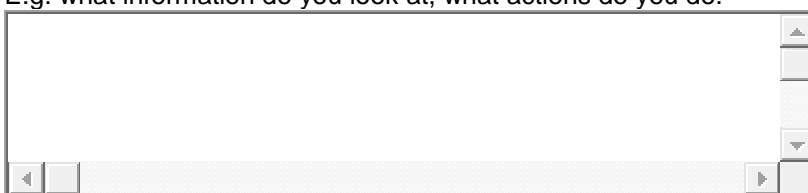
Not at all Very well

8. What are the reasons why you have opened Carat lately?

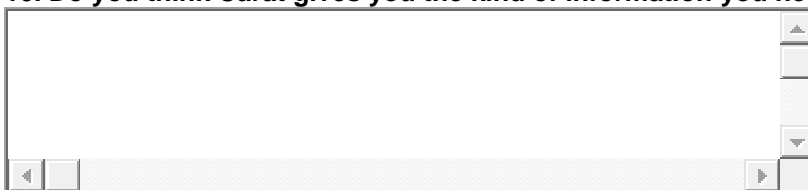
A rectangular text input field with a light gray background and a thin black border. It has a vertical scrollbar on the right side and a horizontal scrollbar at the bottom.

9. What do you do when you open Carat? Why?

E.g. what information do you look at, what actions do you do.

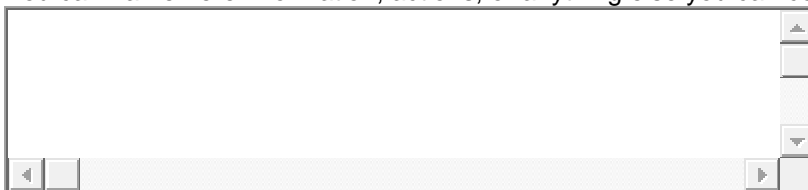
A rectangular text input field with a light gray background and a thin black border. It has a vertical scrollbar on the right side and a horizontal scrollbar at the bottom.

10. Do you think Carat gives you the kind of information you need?

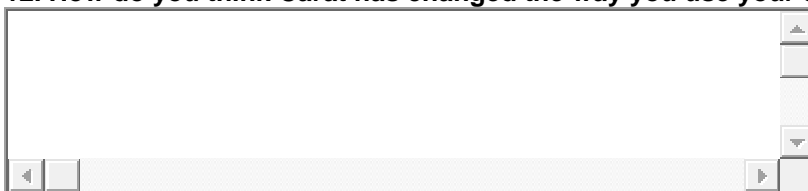
A rectangular text input field with a light gray background and a thin black border. It has a vertical scrollbar on the right side and a horizontal scrollbar at the bottom.

11. What would you like to see in Carat that is not there now?

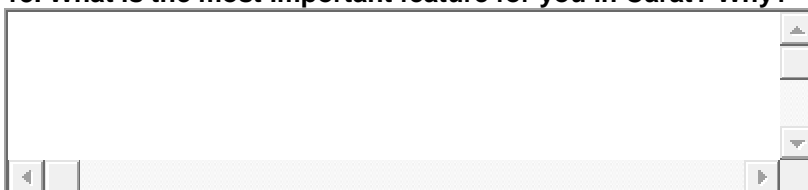
You can name here information, actions, or anything else you can come up with.

A rectangular text input field with a light gray background and a thin black border. It has a vertical scrollbar on the right side and a horizontal scrollbar at the bottom.

12. How do you think Carat has changed the way you use your device?

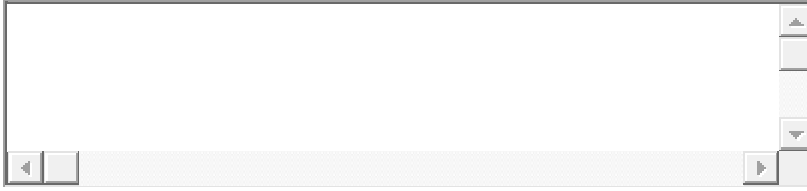
A rectangular text input field with a light gray background and a thin black border. It has a vertical scrollbar on the right side and a horizontal scrollbar at the bottom.

13. What is the most important feature for you in Carat? Why?

A rectangular text input field with a light gray background and a thin black border. It has a vertical scrollbar on the right side and a horizontal scrollbar at the bottom.

14. Is there anything else you want to say?

Any suggestions or any important information about Carat that is not captured by the above questions

A large, empty text input field with a light gray background and a thin black border. On the right side, there is a vertical scroll bar with a small upward-pointing arrow at the top and a downward-pointing arrow at the bottom. At the bottom, there is a horizontal scroll bar with a left-pointing arrow on the left and a right-pointing arrow on the right.